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Existing and Historical Water Monitoring in the Phase 2 Geographic Expansion Area, to 2011

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Canada

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INTRODUCTION

INTEGRATED MONITORING PLAN FOR THE OIL SANDS (PHASE 2)

Recent reports on the oil sands (Lott and Jones, 2010; Royal Society of Canada, 2010) have included criticisms of monitoring performed in the area. Kelly and collaborators (Kelly *et al.*, 2009, 2010) and Schindler (2010) raised questions regarding the adequacy and credibility of existing environmental monitoring programs in the oil sands area. Donahue (2011) discussed government and RAMP (Regional Aquatics Monitoring Program) monitoring in the area, and made suggestions on how to develop robust monitoring programs.

A Federal Oil Sands Advisory Panel was struck to examine monitoring in the oil sands region, (Dowdeswell *et al.*, 2010). The panel report, presented in December 2010, called for establishment and implementation of a more rigorous and effective oil sands monitoring program. In response to this report and other concerns, the Federal Minister of the Environment committed Environment Canada to lead, in collaboration with the Government of Alberta, the development of a preliminary surface water quality monitoring plan (Phase 1) for the lower Athabasca River and tributaries, and to complete this task within 90 days (Environment Canada and Alberta Environment, 2011a).

The result was a conceptual framework for a detailed water quality monitoring plan for the Lower Athabasca River: "Lower Athabasca Water Quality Monitoring Plan – Phase 1" (Environment Canada and Alberta Environment, 2011a), released by the Minister of the Environment in March 2011. The Phase 1 oil sands monitoring plan was developed for water quality, focussing on physical and chemical attributes, primarily in the area of surface-mineable oil sands (see Figure 1). Subsequent steps were intended to expand the plan to a larger geographic area, include other environmental media like air and biodiversity, and ensure the media-specific plans were integrated into a single, holistic, ecosystem-based approach (Environment Canada and Alberta Environment, 2011a).

Alberta also convened a Panel to examine the state of oil sands monitoring and make recommendations for improvements and implementation. In January 2011, a group of independent experts were chosen to help design a provincial scale environmental monitoring system with an initial focus in the Lower Athabasca region (Alberta Environmental Monitoring Panel, 2011). The conclusions and recommendations of the federal Oil Sands Advisory Panel and those of the Alberta Environmental Monitoring Panel were very similar. The Alberta panel added specific recommendations about governance, particularly that Alberta establish an arm's length Alberta Environmental Monitoring Commission (Alberta Environmental Monitoring Panel, 2011).

As well, the province of Alberta struck a Water Monitoring Data Review Committee, to review articles by Kelly *et al.* (2009, 2010), reports by Alberta Environment, and the Regional Aquatics Monitoring Program (RAMP). This panel was charged with examining study designs, data, and statistical approaches, to determine if the conclusions among these reports were consistent and comparable. It was considered that due to the differences in purpose and methods of the studies, their conclusions generally did not conflict, despite occasional differences in interpretations or neglected patterns. Recommendations were made to improve the quality and scientific rigor of water quality monitoring programs (Dillon *et al.*, 2011).

Phase 2 of the oil Sands Monitoring Plan built on and expanded Phase 1 by providing further detailed monitoring designs for an expanded geographic coverage of relevant watersheds and downstream areas, as well as details on the air quality, aquatic and terrestrial ecosystem

components to be monitored. An overview of the Phase 2 monitoring plans is provided in "An Integrated Oil Sands Environment Monitoring Plan" (Environment Canada and Alberta Environment, 2011b). The aquatic portion of Phase 2 was described in the "Integrated Monitoring Plan for the Oil Sands – Expanded Geographic Extent for Water Quality and Quantity, Aquatic Biodiversity and Effects, and Acid Sensitive Lake Component" (Environment Canada and Alberta Environment, 2011c), released in July 2011.

EXPANDED GEOGRAPHIC EXTENT

Phase 2 Expanded Geographic Extent extended the scope of the aquatic monitoring program described under Phase 1 to include other relevant downstream watersheds, including the lower Peace River, the Peace-Athabasca Delta (PAD), Lake Athabasca and the Slave River, culminating in the Slave River Delta. With the expanded geographic area came a significant increase in hydrologic and ecological complexity, including the potential for additional natural and anthropogenic contaminant source contributions, as well as the deposition, dispersion, dilution and degradation that can occur through transport over large geographic scales (Environment Canada and Alberta Environment, 2011b). The complex transboundary nature of drainage across this large area can be seen on Figures 1 and 2 (Figure 11 also illustrates this).

A history of interest in the Athabasca oil sands was compiled by Ferguson (1985). The earliest written descriptions of oil sands are notes by European explorers. Alexander Mackenzie described "bituminous fountains" or pools found on the Athabasca River, which could be mixed with spruce gum and used to treat canoes, and also noted that [near what is now Fort McMurray] "the banks of the river, which are there very elevated, discover veins of the same bituminous quality". Scientific assessment began with geological and geographic investigations by the federal government in the 1870s and 1880s. The Geological Survey of Canada (GSC) examined and assessed the oil sands as part of resource assessment in the west. GSC expedition records described "oil shales" and "tar sands", particularly along the Athabasca between Embarras and the Clearwater. The beginnings of exploitation came with the federal government's reassessment of the importance of petroleum as a resource, beginning about 1912, and included pioneering research by then-GSC employee Sidney Ells. Further research by scientists in Alberta, including the notable work of Karl Clark, led to a field-scale separation plant at Fort McMurray in 1929. Government and private enterprise efforts to commercialize oil sands continued, with operations such as Abasand and Bitumount, and *in situ* test projects. The Great Canadian Oil Sands plant [later Suncor] north of Fort McMurray was completed in 1968. This was followed by another major commercial operation, Syncrude, circa 1974 (Ferguson, 1985).

The Peace River watershed contains another major oil sands deposit, the Peace River oil sands area (see Figures 1 and 2), with 14 projects under production as of this writing (Alberta Energy website). There are areas of natural petrogenic input (tar balls, etc.) next to, and within, the Peace River. Early European explorer and geologic accounts also described oil sands deposits along the Peace River. "On Peace River and Lesser Slave Lake, bitumen was found in a number of places lining cracks in nodules, and at Tar Island in Peace River small quantities of tar are brought to the surface by a spring" (Chambers, 1914). Geologist John Macoun also noted "oil springs" (seeps) on the Peace River (Macoun, 1922).

A particularly important anthropogenic impact on the Peace River and the Peace-Athabasca Delta is the W.A.C. Bennett Dam near the town of Hudson's Hope, British Columbia. The completion of the dam in 1968 and the subsequent flooding of several river valleys formed Williston Reservoir. Some of the lowest recorded water levels on the Peace River in Alberta occurred during the Williston Reservoir filling period, from 1968 to 1971. Since the dam came into full operation in 1972, lower monthly mean flows have occurred during the summer and higher

monthly mean flows during the winter. The ice regime of the Peace River has also been affected by regulation (MacLock *et al.*, 1997).

The Peace and Athabasca Rivers join in the Peace-Athabasca Delta (PAD). In 1982 the delta was recognized by the Convention on the Conservation of Wetlands of International Importance. Complex water movement in the Peace-Athabasca Delta is fundamental to its environmental characteristics. Since the landscape of the delta is relatively flat, many of its waterways can flow in different directions, depending on the relative water levels in different parts of the delta. If the water level in Lake Athabasca is higher than Claire and Mamawi Lakes, water can flow westward into the delta. If Lake Athabasca is low, water flows east out of the delta lakes and into Lake Athabasca. The reversing concept holds true for the major channels that drain the delta: Chenal des Quatre Fourches, Revillon Coupé and Rivière des Rochers. Usually, these three channels flow north to meet with the Peace River and then continue north as the Slave River. However, when the Peace River rises higher than the water level of Lake Athabasca, water flows south from the Peace into Lake Athabasca and the Delta. Flow changes on the Peace River, caused by the Bennett Dam, have reduced both the magnitude and frequency of natural flooding events in the delta, causing many of its perched lakes to dry out (MacLock *et al.*, 1997).

The Expanded Geographic Extent area also includes a second large river delta, the Slave River Delta. Covering an area of about 8,300 km^2 and up to 70 km wide, the Slave River Delta is smaller than the Peace-Athabasca Delta, but is also very important as fish and wildlife habitat, and to the way of life of the local people (English *et al.*, 1996).

CONTEXT OF THIS REPORT

This report, Phase 2 Component 2, is a bibliographic compilation of water-related monitoring programs and activities in the Expanded Geographic Extent prior to the implementation of the Integrated Monitoring Plan for the Oil Sands (Environment Canada and Alberta Environment 2011c). It comprises an information table of parameters sampled by the most relevant ongoing and historical programs and activities, annotated abstracts and descriptions of relevant programs and studies, notes on particularly relevant organizations, and maps of monitoring locations and other information, up to July 2011. This document is a bibliographic tool for locating sources of water quality information, providing a general roadmap to "who has measured what, when, and where?" within the Expanded Geographic Extent. It was not intended to collect or contain data. Although Component 2 was originally designed to cover only water quality and quantity (as in Phase 1), it was expanded to include readily accessible information on fish programs and benthic invertebrate monitoring in the Expanded Geographic Extent.

This report is mainly concerned with monitoring, and was not intended to be an exhaustive list of research published in the primary literature. Long-term water quality monitoring tends to be associated with legislation, policy, interjurisdictional and/or transboundary issues or agreements, and public requirements, and as such, is usually undertaken by various levels of government. Historical monitoring information is frequently found in government reports, which may not be readily accessible through modern library search methods.

In this document, major activities and programs as of July 2011, prior to the Integrated Plan implementation, then historical activities are summarized. Certain organizations that are relevant to activities in the expanded geographic area are also noted. As this report was intended to support the Expanded Geographic Extent section of Phase 2 only, some historic information which does not extend into the Expanded Geographic Extent area may not be included here.

The most important tool in this document is Appendix 1, which includes specific information on parameters sampled by the major monitoring programs and other activities in the Expanded Geographic Extent region up to July 2011. Criteria for inclusion in Appendix 1 were:

- studies that present sampling locations within the area of interest (even if only 1 or 2 among a majority of externally located sites);
- Water quality modeling studies;
- studies concerned with fish and/or benthic community composition. Those reporting fish length measurements, abundance and/or movement are included only if they also assess community composition.

Studies were excluded from Appendix 1 if they were:

- Water/sediment quality-related studies that reported sampling within the area of interest, but only for contaminants typically associated with pulp and paper mill effluent;
- studies that discussed sampling programs within the area of interest but exclusively presented data from previous studies/reports/programs (i.e., do not report new data);
- One-off hydrological measurements (e.g., flow, depth) taken during water/sediment quality and/or fish/benthic focussed studies;
- Databases;
- studies that collected samples for contaminant analysis which were intended to be presented in subsequent (unreferenced) reports.

Some of the studies excluded from Appendix 1, particularly historic documents, are included in the text if they may provide potentially useful information or sources of data on specific topics. Annotated abstracts of these, as well as all studies in Appendix 1, are included under the appropriate subheading.

Water-related long-term monitoring in the oil sands region should be informed by existing and historical monitoring, and focussed studies and activities that have produced data and information over time. Sources and locations of this information are many and disparate. Historic information is important because there is potential for it to be used as reference data, from a time before the current level of oil sands development. Since there is no comparable river system to the Peace-Athabasca-Slave which could be used as a geographic reference, comparing the present conditions to those in the past (i.e., using a temporal reference) is the alternative.

An important aspect to note is that potential temporal reference information depends on the availability of longer-term data. This requires a minimum of at least 5 years to be useful (Reid and Ogden, 2006). For some purposes, even a 5-year dataset is too "noisy", and when searching for trends, longer terms of 10, 15 and 30 years may identify signals (i.e., trends) more reliably (Burt *et al.*, 2008). The value of long-term monitoring is undisputable: for generating data applicable to the legislative and policy purposes, for status and trend analysis, and as the best tool to understand normal variability and distinguish change over the long term (Burt, 1994).

EXPANDED GEOGRAPHIC EXTENT MONITORING AND ACTIVITIES

A: MONITORING AND FOCUSSED STUDIES

A1: LONG-TERM WATER QUALITY AND QUANTITY MONITORING

A1.1: Environment Canada

A1.1.1: Water Quality

In cases where rivers flow from one province to the next, trans-boundary agreements are in place to ensure that adequate water quality and quantity are maintained. Examples of trans-boundary agreements include the Prairie Provinces Water Board (PPWB), Master Agreement on Apportionment (for east-flowing waters) and the Mackenzie River Basin Transboundary Waters Master Agreement (MRBB) (for the Mackenzie and its tributaries). Environment Canada (EC) typically monitors water quality on trans-boundary rivers in provincial boundary reaches, in some cases in partnership with Alberta Environment (AENV). Environment Canada, in partnership with Parks Canada, also monitors water quality in a number of national parks, including the Athabasca River headwaters in Jasper National Park, and sites on the lower Athabasca and lower Peace Rivers, in Wood Buffalo National Park. A site on the Slave River, near Fort Fitzgerald, is monitored in partnership with Alberta Environment.

Prior to 1987, long-term monitoring in Alberta was carried out by what would eventually become Environment Canada. Changes in the precise locations of sampling stations, and lack of accurate georeferencing from the early years causes some difficulty in assessing complete periods of record. However, some long-term sites are relatively stable; for example, Environment Canada database records indicate that sampling on the Athabasca River at the town of Athabasca was conducted from 1961 to 1986, with a total of 305 samples in the database. More information may be available in hardcopy, and while not retrievable within the time constraints of this Phase, may be worth locating in future, for reference/baseline or trend analysis.

Figures 2, 3 and 4 show the long-term water quality monitoring sites operated by Environment Canada in the Athabasca, Peace and Slave River basins. Parameter information is included in Appendix 1. Figure 2 sets regional context, which covers most of the Athabasca, Peace and Slave River drainages. Figure 3 shows the Expanded Geographic Extent area, from the southern portion of Wood Buffalo National Park to Great Slave Lake. Figure 4 is the area of the Peace-Athabasca Delta, which could be a potential sink for any effects from upstream anthropogenic activities. Parameters sampled at EC monitoring sites are listed in Appendix 1.

A1.1.2: Water Quantity

Water quantity (i.e., lake level and river level/discharge) is monitored within Alberta by a network of hydrometric stations operated by Water Survey of Canada. A small number of hydrometric stations are also operated by Alberta Environment, but published within the Water Survey of Canada HYDAT hydrologic monitoring database. (Rick Pickering, Alberta Environment, pers. comm.) In the Peace River basin in B.C., hydrometric monitoring is carried out by Water Survey of Canada, and also by B.C. Hydro in the area around Williston Reservoir (BC Hydro website).

Climate information (e.g., precipitation and air temperature) is monitored at selected sites, which provides useful information for assessing first-order drivers of water quantity and quality (e.g., snow water equivalence of spring snowpack to calculate contaminant loading).

Figures 5, 6 and 7 indicate the location of Water Survey of Canada water quantity monitoring stations in the Athabasca, Peace and Slave River basins. Alberta Environment and Environment Canada climate stations, and Alberta Environment (Alberta Environment Plains Snow Course Data and Historical Rankings [online]), B.C. Environment, and Aboriginal Affairs and Northern Development Canada (Indian and Northern Affairs Canada [Aboriginal Affairs and Northern Development Canada] Snow Survey Data) snowpack measurement sites are also included. Long-term precipitation data (e.g., snowpack depth and snow water equivalence and rainfall) are useful to compare current year precipitation to historical context (above/below average) and to possibly spatially interpolate precipitation data to calculate loading for the region (Greg McCulloch, Water Survey of Canada, pers. comm.). Parameters sampled at water quantity monitoring sites are listed in Appendix 1.

Stream gauging involves obtaining a record of time-varying stage, making periodic discharge measurements, establishing and maintaining a relation between the stage and discharge, and applying the stage-discharge relation to the stage record to obtain a discharge value. Data collection, processing, archiving, and distribution occur under a national standardized approach. Data for the current federal-provincial network (along with discontinued sites) is stored in the National Water Survey of Canada HYDAT database (Water Survey of Canada Archived Hydrometric Data Online) and made readily available through various media, including a public web page.

http://www.ec.gc.ca/rhc-wsc/

Historical sediment monitoring at Water Survey of Canada hydrometric sites is described in subsection B.5.

Current scientific research activities by Environment Canada are following up on the issue of decreasing trends in water availability highlighted in a paper by Schindler and Donahue (2006). These assess the issues of water availability/water balance and the sustainability of streamflow to the lower Athabasca River and Delta. In particular, the potential effects of rapidly increasing upstream development and climate variability/change on seasonal streamflows and on eco-hydrologically relevant hydrograph parameters (e.g., quantity and timing of annual peak and low flows) are being investigated. Streamflow along the mainstem of and tributaries to the Athabasca River is being examined to determine if reported decreasing flow trends are discernible in the alpine, foothill and lowland regions of the watershed, and if so, what are the causal factors driving the observed trends (e.g., large-scale climate signals, land-use change, water uses, etc.). The Federal Government has responsibilities related to transboundary water and flow through National Parks and First Nation Land located downstream of the Embarras station.

A1.1.3: Fish Contaminants

A National Fish Contaminants Monitoring and Surveillance Program (FCSMP) was begun by Environment Canada in 1977. For much of the program's history, the focus of monitoring activities was centered in the Canadian waters of the Great Lakes, but in 2006, the program was expanded under Canada's Chemicals Management Plan (CMP) to include water bodies across Canada. The FCMSP provides data on the concentrations of contaminants of emerging concern in the environment and any tendency to bioaccumulate, to inform risk assessments under the Canadian Environmental Protection Act (CEPA) and from which to assess the effectiveness of

regulations aimed at reducing the concentrations of contaminants in the environment. Fish are now collected annually from all CMP lakes, aged and whole body homogenates of each individual fish from the lake in question are analyzed for polybrominated diphenyl ethers (PBDEs) (all congeners), 28 metals (National Laboratory for Environmental Testing metals suite including mercury), and stable isotope ratios of C and N (Environment Canada National Fish Contaminants Monitoring and Surveillance Program website).

Lake trout and burbot are monitored for metals and organochlorine contaminants in Great Slave Lake under the Northern Contaminants Program (Evans *et al.*, 2005), and those fish are also analyzed under the CMP. Western Lake Athabasca is included as a sampling site for a polybrominated diphenyl ethers (PBDE) monitoring study, with mercury also being measured. Analyses have been based on lake trout, but northern pike and walleye have been added more recently. Lake trout from eastern Lake Athabasca, Cold Lake, Reindeer Lake and Great Bear Lake are also to be examined for contaminants. It is expected that monitoring of lake trout, walleye and pike in western Lake Athabasca for mercury and PBDE trends should continue (Marlene Evans, Environment Canada, pers. comm.).

Results from these programs are generally found in publications by study authors (e.g. Evans *et al.*, 2005), and publications or reports relevant to the Expanded Geographic Extent are captured as individual studies in Appendix 1.

A1.2: Alberta Environment

A1.2.1: Water Quality

Following the creation of Alberta Environment (AENV) and the development of provincial legislation for regulating point-source discharges in the 1970s, field sampling was designed to include non-point source issues associated with logging, agriculture, mining, urban runoff and atmospheric deposition (Alberta Ministry of Environment Surface Water Quality Program website).

Until 1987, long-term water quality sampling was performed by Environment Canada (or precursor). In 1987, responsibilities for sampling in areas inside Alberta's borders shifted to Alberta Environment (Alberta Environment, 2011).

Alberta's Long-Term River Network (LTRN) site about 200 kilometres downstream of Fort McMurray has data available from 1968, but the station shifted from the Embarras airstrip (about 15 km downstream of the EC site monitoring site at 27th Baseline, shown in Figure 2) to 25 km further downstream at Old Fort. This occurred around 1990. For the summer season the LTRN site has remained at Old Fort. In winter the sampling is moved to where the winter road crosses the main channel, for logistic and safety reasons (Rod Hazewinkel, Alberta Environment, pers. comm.).

Alberta Environment's Long-Term River Network also includes a number of stations on the Peace River, both above and below the Peace River oil sands deposit. As mentioned in the Introduction, the Peace River deposit is not subject to open-pit mining. However, the river does pass through areas where petrochemicals may enter the watershed, either through natural or anthropogenic processes.

Alberta Environment long-term water quality monitoring sites are indicated on Figures 2, 3, and 4. As far as can be determined at this point, the Alberta Environment database contains all data (including many AOSERP, NRBS and NREI data, see relevant sections below) from when the

database was initially developed jointly with Environment Canada (Rod Hazewinkel, Alberta Environment, pers. comm.). Parameters sampled at AENV LTRN monitoring sites are listed in Appendix 1.

A1.3: BC Environment

The Water and Air Monitoring and Reporting section, in the Environmental Quality Branch of the Environmental Protection Division of B.C. Environment, is responsible for water and air monitoring and reporting. An Environmental Monitoring System (EMS) is the ministry's primary monitoring data repository. The system was designed to capture data covering physical/chemical and biological analyses performed on water, air, solid waste discharges and ambient monitoring sites throughout the province. It also contains related quality assurance data. Samples are collected by either ministry staff or permittees under the Environmental Management Act and then analyzed in public or private sector laboratories. The Environmental Monitoring System Web Reporting (EMS WR) provides read-only access to data in the Environmental Monitoring System. The purpose of EMS WR is to give registered ministry staff, B.C. health authorities and qualified environmental professionals access to provincial environmental-quality sampling data, and to allow water purveyors access to specific drinking-water data in EMS. Direct access to EMS is restricted to ministry staff. However, the related data are available to the general public on request. A processing charge is applied to such data requests (BC Environment website).

http://www.env.gov.bc.ca/epd/wamr/ems_internet/index.html

BC Environment water quality sampling sites in the upper Peace River drainage are indicated on Figure 2. Industrial sites are not included, although there are a number of permitee monitoring sites in the area.

A1.4: Aboriginal Affairs and Northern Development Canada (AANDC)

This federal department has had a number of name changes over the years, and references to reports may give various departmental names (e.g., Indian and Northern Affairs Canada - INAC; Department of Indian Affairs and Northern Development - DIAND).

A1.4.1: Aboriginal Affairs and Northern Development Canada Water and Sediment Quality Programs in the Slave River and Delta

Since 1982, water quality grab samples have been collected twice a year from several sites in the South Slave District, including the Slave River at the mouth (Slave River at Delta site: downstream of Nagle Channel and upstream of Old Steamboat Channel, just before the Slave River divides into the delta), Slave River at Fort Smith (shore) (see Figures 2 and 3), plus some other sites that are outside of the scope of the Expanded Geographic Extent. These samples were collected over the years by the South Slave District Water Resource Officer, to provide a general idea of water quality in the area. The samples were analyzed for conventional water quality variables, nutrients, and metals.

The Slave River Environmental Quality Monitoring Program (SREQMP) was established in 1990 to characterize the baseline conditions of the aquatic ecosystem in the Slave River at Fort Smith, Northwest Territories. SREQMP was a five year multimedia sampling program, operating from

1990 to 1995, to characterize baseline conditions of the aquatic ecosystem in the Slave River at Fort Smith, Northwest Territories (NWT), Canada. The comprehensive nature of the program made it the first of its kind in the Northwest Territories. The SREQMP was a cooperative program among the Water Resources Division of the Department of Indian Affairs and Northern Development, the Government of the Northwest Territories' (GNWT) Department of Renewable Resources, the Department of Fisheries and Oceans (DFO) and Environment Canada (EC). The objectives of the Slave River Environmental Quality Monitoring Program were to:

- address concerns of northerners regarding possible contamination of fish, water and suspended sediment from pulp mill, hydrocarbon and agricultural developments upstream; and
- provide baseline data on contaminant levels in fish, water and suspended sediment at the NWT boundary to support transboundary water negotiations between Alberta and the NWT (Sanderson *et al.*, 1997).

Water samples (both centrifugate and grab) were analysed to address drinking water concerns, for comparison to water quality guidelines and to set water quality objectives in transboundary negotiations. Suspended sediment samples were collected because metals and organic contaminants tend to adsorb to the smaller particulate fractions in aquatic environments. As little or no historic sediment quality data were available for the Slave River, this monitoring also helped meet the program's goal of establishing baseline environmental conditions. Fish were sampled because they serve as a good early warning system for contamination in an aquatic environment, due to their ability to bioaccumulate environmental pollutants. Fish can be a large part of people's diet in the NWT (Sanderson *et al.*, 1997).

Grab water samples were analyzed for 37 physical, biological and chemical (major ions, nutrients and metals) variables, while centrifugate water samples were tested for 29 physical and chemical variables, as well as selected organic compounds including extractable organic chloride (EOCl), 44 chlorinated phenolics (CPs), 13 pesticides, total polychlorinated biphenyls (PCBs), and 17 polycyclic aromatic hydrocarbons (PAHs) congeners. Sediment samples were tested for total organic carbon (TOC), metals, EOCl, chlorinated phenolics, dioxins and furans, pesticides, PCBs and PAHs (see Appendix 1). Samples were collected from both the Slave River and control sites. Sampling took place from 1990 to 1995. Results are summarized in Sanderson *et al.*, (1997).

Since the SREQMP, further intensive sampling has taken place on the Slave River every five years. From 2000 to 2007, grab and centrifugate water samples, along with suspended sediment samples, were collected on eight occasions during 2001 to 2003 and during 2006 to 2007. Samples were collected from the midpoint of the Slave River at Fort Smith and analysed for a suite of conventional and organic variables similar to those evaluated in the original study (Juanetta Sanderson, AANDC, pers. comm.; Sanderson *et al.*, in prep).

An examination of the hydrology of the South Slave Region can be found in Kokelj (2003), who discusses hydrometric data from the Slave River at Fitzgerald, as well as hydrometric monitoring at a number of sites in the region south of Great Slave Lake, (most of which are outside of the scope of the Expanded Geographic Extent).

A1.4.2: AANDC Fish Studies on the Slave River

Fish samples were collected from the Slave River as part of three separate studies. Their objectives were to provide baseline data on mercury, hydrocarbon and organochlorine levels in fish from transboundary rivers, in support of transboundary negotiations.

A study on mercury in fish study began in 1988 and continued for three years. Walleye and northern pike were collected downstream of the Alberta-NWT border in the Slave and Hay Rivers, as well as from Leland Lake (Grey *et al.*, 1995). Samples were analyzed by the Freshwater Institute in Winnipeg for total mercury levels and methyl mercury. Grey *et al.* (1995) provides a summary of these values and compares them to other sites in the NWT.

Studies examining organic contaminant levels and microsomal enzyme activity in fish from the Slave River were carried out in 1988 and 1989 by DIAND (AANDC) Water Resources Division in partnership with the Department of Fisheries and Oceans (DFO). The analyses focussed on derivatives (e.g., naphthalene, phenanthrene) most relevant to the composition of northern Alberta oil sands wastewater and its potential impacts. In the fall of 1988, burbot and lake whitefish were collected in the Slave River at Fort Smith. These fish were analyzed for low-boiling-point hydrocarbons and mixed-function oxygenase (MFO) enzymatic activity assays. In addition, the proximate composition (percentage of moisture, lipid, ash and protein) and biological factors of the fish were recorded and a taste panel conducted. In 1989, burbot and walleye livers were collected, and the samples analyzed for MFOs. Muscle samples from the 12 fish whose livers showed the most enzymatic activity were preserved and analyzed for hydrocarbon content. In addition, bile samples were analyzed for PAH metabolites. The results from these two years of sampling are summarized in Lockhart *et al.* (1988) and Lockhart *et al.* (1991).

In the fall and winter of 1988 and 1989, burbot and longnose suckers were collected by DIAND (AANDC) Water Resources and DFO, from sites on the Slave River near Fitzgerald, Alberta and Fort Smith, NWT, and analyzed for organochlorines, PCBs, and chlorinated dioxins and furans. 1988 results are summarized, and raw data sets are included in appendices, in Whittle (1989).

During community consultations in 1992 and 1993, the citizens of Fort Resolution expressed concerns about the quality of the fish from Great Slave Lake in the Resolution Bay and the old Pine Point pump house areas. To address these concerns, DIAND (AANDC) Water Resources Division, with the cooperation of the DFO, evaluated the levels of heavy metals in fish from the area. Fish were collected in 1992 near the community of Fort Resolution and during the fall of 1993 in the vicinity of Dawson Landing and Pine Point, with the help of local fisherman. All samples were analyzed for 28 elements including arsenic, cadmium, copper, lead, mercury, nickel and zinc. Fish from these areas were found to be robust, with very low concentrations of metals (Lafontaine, 1997). The study was continued in Peddle *et al.* (1996).

A1.4.3: Northern Contaminants Program

In the early 1990s, the Arctic Environmental Strategy investigated contaminants in the Canadian arctic and considered pathways and processes. The study was very comprehensive, considering fresh and marine waters, the atmosphere, sediments, and biota and contributed to various assessments including the international Arctic Monitoring and Assessment Programme (AMAP). The Arctic Environmental Strategy was succeeded by the Northern Contaminants Program (NCP).

The Northern Contaminants Program (NCP) was established in 1991 in response to concerns about human exposure to elevated levels of contaminants in wildlife species that are important to the traditional diets of northern Aboriginal peoples. Early studies found a wide variety of substances – persistent organic pollutants (POPs), heavy metals, and radionuclides – many of which had no Arctic or Canadian sources, but which were, nevertheless, reaching unexpectedly high levels in the Arctic ecosystem, many of them through Long Range Aerial Transport. The NCP funds research into contaminant-related science in the North. Activities to be funded by the Program fall under five subprograms: human health; environment; education; and national/

regional coordination and Aboriginal partnerships. The geographic focus of the NCP is the Yukon, Northwest Territories and Nunavut (Northern Contaminants Program website, July 2011[1]).

Links to reports and publications of research and monitoring conducted under the Northern Contaminants Program, and also the Arctic Monitoring and Assessment Programme are available on the Northern Contaminants Program website. Research and monitoring funded under the NCP that falls within the Expanded Geographic Extent area (Peace-Athabasca Delta, Slave River and Delta) has been captured as research publications (e.g., Evans *et al.*, 2005) or reports (e.g., Evans *et al.*, 1998b) in Appendix 1.

A1.5: Wood Buffalo National Park

Wood Buffalo National Park (WBNP) of Canada spans the Alberta/Northwest Territories boundary, and is Canada's largest national park, at 44,807 square kilometres, a UNESCO World Heritage Site and the second largest national park in the world. The Park was originally created in 1922 to protect the last free roaming herds of wood bison in northern Canada. It was later identified as critical habitat for the endangered whooping crane and in 1982 the Peace-Athabasca Delta and the whooping crane nesting area were added to the RAMSAR List of Wetlands of International Importance. The biological productivity and diversity of the Peace-Athabasca Delta depends upon regular inputs of water and nutrients from the Peace, Athabasca and Birch Rivers and Lake Athabasca. Impacts of external stressors and climate change on water quantity and water quality are of primary concern. Local people are reporting that ecological changes (such as changing plant communities, water levels, and use by wildlife) have affected their traditional use of, and connection to, the area (Parks Canada, 2010).

Wood Buffalo National Park has an active monitoring program and is gathering results for four ecological integrity indicators that are in place: Forest, Delta, Wetlands, and Streams and Rivers (see Figure 8). Water-related indicator ecosystems and their measures (including agencies involved) include:

- Delta - hydrology of Lake Claire, Lake Athabasca (Alberta Environment), historic flood record dating back to 1850's (WBNP), wetland vegetation transects (WBNP), fish community (EC and other agencies);
- Wetlands (primarily the whooping crane nesting area, 5,000 km^2 in the northern part of the park) - whooping crane nesting pairs (total count by Canadian Wildlife Service and WBNP), hydrology of the wetlands is monitored by WBNP, an amphibian indicator is under development;
- Rivers - water quantity from Water Survey of Canada (Environment Canada) stations at Peace Point (Peace River), below Fort McMurray (Athabasca River) and on the Birch River and 2) water quality for the Peace and Athabasca Rivers undertaken by EC/WBNP cooperative agreement (Jeff Shatford, WBNP, pers. comm.)

Terrestrial, air and wildlife components are not listed here, but can be found in the Wood Buffalo National Park's Management Plan (Parks Canada 2010). The Park's management plan requires initiation of resource-monitoring programs, including the Peace-Athabasca Delta Ecological Monitoring Program (PADEMP) (see section D2, below). This program is to be fully developed by

[1] Editor's note: after the writing of this document, the AANDC website changed. The Northern Contaminants Program can now be accessed through http://www.aadnc-aandc.gc.ca/eng/1323297155186/1323297233327

2015. As the park ecological integrity monitoring program is refined, traditional knowledge and western science will be further integrated into monitoring activities (Parks Canada, 2010).

A1.6: Regional Aquatics Monitoring Program

The Regional Aquatics Monitoring Program (RAMP) is an industry-funded, multi-stakeholder environmental monitoring program initiated in 1997. The overall mandate of RAMP is to determine, evaluate, and communicate the state of the aquatic environment and any changes that may result from cumulative resource development within the Regional Municipality of Wood Buffalo. RAMP integrates aquatic monitoring activities across different components of the aquatic environment, geographical locations, and Athabasca oil sands and other developments. The coordination of monitoring efforts among RAMP members results in a comprehensive, regional and publicly-available database that may be used by operators for their environmental management programs, compliance with environmental requirements of regulatory approvals, assessments of proposed developments, as well as by other stakeholders interested in the health of the aquatic environment in the Athabasca oil sands region (RAMP, 2011).

RAMP is governed by a multi-stakeholder Steering Committee. Membership in this decision-making body is comprised of oil sands companies and other industries, Aboriginal representatives, and government agencies (municipal, provincial and federal). RAMP also has a Technical Program Committee responsible for the development and review of the RAMP technical monitoring program from year to year, that is divided into discipline-specific sub-groups that develop and review their component for integration into the overall monitoring program. Investigators (the Hatfield RAMP Team, consisting in 2010 of Hatfield Consultants Partnership, Kilgour and Associates Ltd., and Western Resource Solutions) primarily carry out the fieldwork, data analysis and reporting (RAMP, 2011).

In 2010, RAMP focussed on six components of boreal aquatic ecosystems (other aspects that are not water-related are not examined here):

- Climate and Hydrology monitors changes in the quantity of water flowing through rivers and creeks in the RAMP study area, lake levels in selected water bodies, and local climatic conditions;
- Water Quality in rivers, lakes and some wetlands reflects habitat quality and potential exposure of fish and invertebrates to organic and inorganic chemicals;
- Benthic Invertebrate Communities serve as biological indicators and are important components of fish habitat, and Sediment Quality is a link between physical and chemical habitat conditions to benthic invertebrate communities. These are measured in rivers, lakes and some wetlands;
- Fish Populations in rivers and lakes serve as biological indicators of ecosystem integrity and a highly-valued resource in the Athabasca oil sands region; and
- Acid-Sensitive Lakes undergo monitoring of water quality in order to assess potential changes in water quality as a result of acidification.

While most of the RAMP program is concentrated in the surface-mineable oil sands, which is outside of the scope of Phase 2 Expanded Geographic Extent proper, some sampling for benthic invertebrate communities and sediment is done by RAMP in the Athabasca Delta. Figures 9 and

10 show RAMP benthic invertebrate and sediment sampling sites relevant to the Expanded Geographic Extent. Parameters sampled are indicated in Appendix 1.

A1.6.1: RAMP Benthic Invertebrate Communities

RAMP focuses on characterizing benthic invertebrate communities on the basis of total abundance, taxonomic richness, and diversity, in areas downstream of focal projects relative to upstream of those projects. This monitoring is focused on tributaries of the Athabasca River and regional wetlands (shallow lakes). Historically, sampling was also conducted on the mainstem Athabasca River but was discontinued in 1998 because of problems related to the transient/shifting nature of bottom sediments. Samples are also collected from four areas within the Athabasca River Delta (ARD). The ARD is an area of significant sediment deposition and is considered to have the potential to be affected by long-term development (RAMP, 2011).

Benthic invertebrate community samples were taken from four depositional reaches in the ARD in fall 2010:

- Depositional test reach BPC-1 in Big Point Channel, sampled from 2002 to 2005 and 2007 to 2010;
- Depositional test reach FLC-1 in Fletcher Channel, sampled from 2002 to 2005 and 2007 to 2010;
- Depositional test reach GIC-1 in Goose Island Channel, sampled from 2002 to 2005 and 2007 to 2010; and
- Depositional test reach EMR-2 in the Embarras River, sampled for the first time in 2010 (RAMP 2011).

Benthic invertebrates were sampled based on methods used previously by Golder (2003a) and RAMP (2009). Five replicate Ekman grab samples were obtained along the ARD channels (10 replicates are normally taken at other depositional sampling sites). Supporting variables were also measured (wetted and bank full channel widths (visual estimate); field water quality measurements (dissolved oxygen, conductivity, temperature, pH); velocity; water depth; substrate particle size (visual estimates expressed as a percentage); and additional Ekman grabs at depositional sites for sediment analysis (TOC, metals, PAHs and particle size) (RAMP, 2011).

Endpoints calculated for every benthic invertebrate sample were: Abundance (total number of individuals/m^2); Taxon richness (number of distinct taxa); Simpson's Diversity Index; Evenness; and Percent EPT (Ephemeroptera, Plecoptera, Trichoptera). Measurement endpoints were then averaged for each reach or lake for the purpose of illustrating time trends. Analysis of variance (ANOVA) was used to test for variations over time for reaches or lakes that have been exposed to oil sands development since 1997. Possible changes in benthic invertebrate communities were evaluated by comparing measurement endpoints in reaches designated as "test" to upstream baseline reaches and/or to pre-development conditions with ANOVA. The ARD was considered unique in the analysis because there are no true regional baseline reaches that provide an adequate comparison. Baseline condition for the ARD habitat was considered to be all of the previous data from 1998 to 2009 (RAMP, 2011).

A1.6.2: RAMP Historic Invertebrate Studies Review

An extremely useful RAMP report is a review and analysis of historical benthic invertebrate data for rivers and streams in the oil sands region (Golder, 2003b). Previous benthic surveys generated a large amount of data in water bodies throughout the Oil Sands Region. A review of available historical data was undertaken to facilitate refinement of the RAMP benthic monitoring program based on experience gained by previous studies and to summarize baseline data for future comparisons and assessments of trends. The objective of the report was to provide an overview of the available historical benthic invertebrate data (up to and including the 2001 RAMP survey), with an emphasis on the Athabasca River, its major tributaries and small streams (Golder, 2003b).

Previous benthic studies were included in the review if they collected quantitative benthic community data using standard sampling devices and reported the raw data or provided a summary of the data. Characteristics of each study were summarized and the raw data for rivers and streams were entered into electronic spreadsheet files. Sites were mapped and renumbered. Data sources and site locations for standing waters were provided, but data summaries were not provided. Habitat features, key benthic community variables, and seasonal and year-to-year variation in benthic community characteristics were summarized for studies that sampled natural substrates in the Athabasca River, the MacKay, Muskeg and Steepbank Rivers (three tributaries in the main development area), small streams north of Fort McMurray, and streams and rivers south of Fort McMurray. Species lists were also prepared (Golder, 2003b). Most of the historical data appeared to be of acceptable quality and were collected using standard benthic sampling devices that are still widely used. The majority of the available historical data were compiled into electronic format for potential future analysis (Golder, 2003b).

A particularly useful aspect of this RAMP review is that a number of internal industry reports, which are relatively inaccessible, are summarized. Some grey-literature provincial government reports, which are also difficult to access, were included. In addition, data prepared in electronic format constitutes a valuable resource for invertebrate scientists.

A1.6.3: RAMP Sediment

Since 2006, sediment quality has been monitored by RAMP in conjunction with the Benthic Invertebrate component, to provide supporting data for interpretation of benthic invertebrate monitoring results. Sediment samples are collected from the most downstream sampling location in each depositional river reach sampled for benthic invertebrates, and from each of the lakes and wetlands sampled for benthic invertebrates. At each station, 2 to 4 grabs of sediment are collected with an Ekman dredge. Grab samples are homogenized into a single composite sample (RAMP, 2009).

. Sediment samples are submitted to analytical laboratories for analysis of the following variables:

- Physical variables — Particle size distribution: % sand, silt, and clay;
- Carbon content—total inorganic carbon, total organic carbon, total carbon;
- Organics—BTEX (benzene, toluene, ethylene, xylene), hydrocarbons by size class (CCME 4-fraction total hydrocarbons; C6-C10, C10-C16, C16-C34, and C34-C50), total hydrocarbons;
- Total metals;

- Target Polycyclic Aromatic Hydrocarbons (PAHs), and Alkylated homologues;
- Toxicity—survival and growth of the amphipod *Hyalella azteca*, and survival and growth of *Chironomus tentans* midge larvae.

Sediment quality data analysis focuses on key measurement endpoints that have been identified as significant by oil sands Environmental Impact Assessments (EIAs), being of special concern or interest in the oil sands region, or of significance to other RAMP components. Sediment quality is assessed by comparing measured results to historical, pre-development, and regional baseline values, to identify any changes that have occurred and to identify stations with sediment quality that is outside the range of natural variability. The relationship between sediment quality and benthic invertebrate measurement endpoints is assessed using statistical correlation analysis to identify those habitat features that consistently affect benthic invertebrate community composition (RAMP, 2011, RAMP website).

Resources that had been allocated originally to sediment sampling on the Athabasca River for the 2006 sampling season were instead reallocated to a one-time, extensive study of sediments within the Athabasca River Delta. A total of 11 stations were sampled at that time, which included 3 of the long-term stations (BPC, FLC, GIC) and 8 new stations (RAMP, 2006).

As of July 2011, RAMP had 3 active stations in the Delta where sediment quality data are collected: Big Point Channel (BPC-1) 1999-2003, 2005, 2007-2010; Goose Island Channel (GIC-1) 2001-2003, 2005, 2007-2010; and Fletchers Channel (FLC-1) 2001-2003, 2005, 2007-2010. As well there is a station on the Athabasca near the delta (ATR-ER) 2000-2005, 2007-2010 and a station on the Embarras River near the delta (EMR-2), which was sampled in 2005 and then most recently in 2010 (Wade Gibbons, Hatfield Consultants, pers. comm.).

Sediment sampling in the Athabasca River mainstem was discontinued in 2005. Sediment accumulation does not generally occur in the mainstem, largely because of flushing during freshet, when average discharge increases from about 125 to 2,000 m^3/s. Sediment sampling efforts were shifted to the Athabasca River Delta, a depositional area where the quality of sediments that accumulate over time can be monitored. In 2006, the sediment quality component was integrated with the benthic invertebrate component, and sediment sampling in erosional reaches was discontinued. Sediment quality in benthic invertebrate depositional reaches is evaluated to assess benthic invertebrate habitat quality and whether accumulating fine sediments are changing over time in ways that may be related to oil sands operations or other processes (RAMP, 2011, RAMP website).

A1.6.4: RAMP Fish Populations

The goal of the RAMP Fish Populations component is to monitor the health status of fish populations within the Athabasca oil sands region. Monitoring activities focus on the Athabasca River and its main tributaries potentially influenced by local projects. RAMP conducts a range of monitoring activities that assess and document ecological characteristics of fish populations, chemical burdens, and habitat use in the Athabasca oil sands region. These include fish inventories; tissue sampling for organic and inorganic chemicals; monitoring of fish health through evaluation of performance indicators (physical condition, population age, and length/weight comparisons) in sentinel fish species; and monitoring of spring spawning use of tributary habitat (RAMP, 2011).

Most of the extensive fish sampling done by the RAMP is in the surface-mineable oil sands area, which is outside of the Expanded Geographic Extent scope. RAMP does present data from a set

of four lakes in the Richardson back-country north of the Firebag River basin, collected in partnership with Alberta Sustainable Resource Development, under the heading of 2009-2010 RAMP Regional Lakes Sampling Program (RAMP, 2011). As these are close to the Expanded Geographic Extent area, information on this portion of the RAMP Fish Populations component is summarized below.

In 2009, tissue studies were performed on a sacrificed subsample of fish captured during Alberta Sustainable Resource Development's (ASRD's) fish population survey on lake whitefish, walleye and northern pike in an unnamed lake known locally as "Jackson" Lake located in the Richardson backcountry north of Fort McMurray. Sampling in the lake took place between September 14 and September 20, 2009 during the Fall Walleye Index Netting program conducted by ASRD. Fish were collected by ASRD using multi-mesh gill nets, measured on-site for fork length (± 1 mm) and total weight (± 1 g), evaluated for sex and stage of maturity, and ageing structures were removed from predator species for analysis by personnel at ASR. The tail sections (between the last rib and end of the caudal peduncle) were then removed, placed on dry ice, and transported to Fort McMurray where they were stored in a deep-freeze. Tissue sample wet weights were recorded for the calculation of total mercury concentration, and samples were shipped to Flett Research (Winnipeg, Manitoba) for mercury analysis. In 2010, tissue studies were performed on a subsample of fish captured during Alberta Sustainable Resource Development's fall walleye index netting program for lake whitefish, walleye and northern pike in three regional lakes, Brutus Lake, Net Lake, and Keith Lake, in the Richardson backcountry north of Fort McMurray. Target species, sample numbers, and size classes were similar to the above study, as were the field and lab methods used (RAMP, 2011).

Mercury concentrations in northern pike and most walleye from Brutus Lake in 2010 exceeded Health Canada guidelines for subsistence fishers, and mercury concentrations in two walleye exceeded the guidelines for general consumers. Mercury concentrations in lake whitefish were below any Health Canada consumption guidelines. Mercury concentrations in lake whitefish and northern pike from Keith Lake were below any Health Canada consumption guidelines. Mercury concentrations in all captured walleye and all but one northern pike from Net Lake in 2010 exceeded the Health Canada guideline for subsistence fishers. With the exception of two fish, mercury concentrations in lake whitefish were below any Health Canada consumption guidelines. Overall, the mercury concentrations in fish sampled from Net Lake were higher in northern pike and walleye compared to mercury concentration in fish from other regional lakes (RAMP, 2011).

Lake Claire was part of the regional lakes program in 2003. Lake whitefish, walleye and northern pike were collected from Lake Claire using gillnets, by a member of the Fort Chipewyan community in December 2002. Individual and/or composite tissue samples were collected for mercury analysis. Mercury levels were highest in northern pike muscle, and lower in walleye and whitefish, but sample sizes were too small to perform any statistical analysis (RAMP, 2004).

A1.6.5: RAMP Historical Fish Studies Review

A review of existing information for tributaries of the Athabasca River in the Oil Sands Region was conducted by RAMP in 2004: to construct a database containing fisheries information from past fisheries reports; produce fish species distribution maps for the tributary watersheds; synthesize existing data and provide an overview of fish communities and fish habitats in tributary watersheds; provide data for comparison with RAMP monitoring data for trend analysis; and identify knowledge gaps and provide recommendations for future work to improve RAMP (Golder, 2004). Independent studies, EIA assessments, consultant reports, and governmental and non-governmental documents, as well as those prepared for the Alberta Oil Sands Ecological Research Program and the Northern River Basins Study were examined. For larger watersheds

with sufficient existing information, the RAMP summary was divided into watercourses that comprise the watershed. A Microsoft Access database was designed to store, sort and query the historical information and retains fields for watercourse location, water quality, habitat description, habitat use, fish community and population structure (Golder, 2004). This RAMP review provides another valuable resource for fish scientists looking for information in the oil sands area.

A1.6.6: RAMP Water Quality, Climate and Hydrology

RAMP has a large network of water quality monitoring sites, conducts flow measurements at seasonal WSC hydrometric stations during winter and operates some of its own hydrometric stations (in some cases taking measurements at deactivated Water Survey of Canada stations). RAMP also has some climate stations and performs snowpack measurements (RAMP, 2011). The RAMP water quality, hydrometric and climate station network as of July 2011 did not extend into the delta, so these components of RAMP remained outside of the scope of the Phase 2 Expanded Geographic Extent. RAMP (2011) indicated a water quality site coded ATR-OF at Old Fort, however, this is Alberta Environment LTRN site AB07DD0010 (see Figure 3). Some sampling was done by RAMP in the Delta area in the past, as follows:

- ATR-ER Upstream of the Embarras River (cross-channel composite). Sampled in 2000 and 2001 as an indicator of downstream water quality. Eliminated due to its proximity to AB07DD0010 (ATR-OF). Sampled in 1999 (winter), 2000, 2001, 2004;
- EMR-1 Embarras River (mid-channel grab). Sampled once in 2003, to assess differences between Embarras River and Athabasca River water quality. Sampled in 2003;
- ARD-1 Big Point Channel (cross-channel composite). Sampled irregularly, given that monthly water quality data are collected nearby by AENV at upstream station ATR-OF. Sampled in 1999 (summer), 2000, 2001, 2003, and 2004.

All stations were sampled in the fall except in 1999 where noted (RAMP, 2009, RAMP website). Water quality parameters sampled for the RAMP program are listed in Appendix 1.

A2: MAJOR FOCUSSED STUDIES AND RESEARCH

The following is a summary of recent major focussed studies or research. This is not intended to be an exhaustive list of all primary literature, but a summary of the most notable work in the area of interest for the Phase 2 Expanded Geographic Extent that is water-related, in the lower Peace, Peace-Athabasca Delta, and Slave River and Delta.

An important document recently created under the Peace-Athabasca Delta Ecological Monitoring Program (PADEMP) (see section D2, below) is a "Synthesis of Ecological Information Related to the Peace-Athabasca Delta" (Köster *et al.*, 2010) It summarized the ecological information on the PAD obtained from past and present monitoring and research programs, assessed the status and trends of key environmental components, and provided recommendations for future monitoring in the PAD. Terrestrial, air and wildlife as well as water-related information were included (Köster *et al.*, 2010).

Andrishak and Hicks (2011) used a detailed one-dimensional network hydraulic model of the Athabasca River Delta (the southern portion of the Peace Athabasca Delta) to show how variable streamflow and ice cover conditions affected how water flowed through the major channels that

move water to Lake Athabasca and the rest of the delta. A channel network model, based on measurements at the main channel junctions, was within 3% of actual measured values. At the three main flow-split junctions, flow simulations at varying discharge, Lake Athabasca water level, and ice thickness values were performed to model their impact on the percentage of flow carried by each channel. Each junction showed a unique response in this modelling, related to physical geometry and location of that junction within the delta. Simulations for the historical period 1960–2007 demonstrated that water demand on the Athabasca River upstream of the PAD could affect the availability of fish habitat in winter (Andrishak and Hicks, 2011).

Donald and Sardella (2010) studied female goldeye, looking at concentrations of trace metals in gravid ovaries and in muscle. Goldeye have slow annual growth and a long life span (maximum longevity of 30 years). The hypothesis was that adult fish with these life-history characteristics would maintain stable concentrations of metals in their tissues with higher levels of essential elements compared with those that are potentially toxic. The concentration of most metals in muscle of adult female goldeye was similar at all ages, suggesting that uptake and excretion of most metals were equal, with mercury as a notable exception. Total mercury concentrations in adult fish muscle increased throughout life. Mercury concentrations in ovaries were only 7% of the concentrations in muscle. Concentrations of Al, Ba, La, V, and Mn were significantly greater in muscle of juveniles and in ovaries than in muscle of adults. Concentrations of 13 metals were higher in ovaries relative to muscle, seven were similar, and four were depleted. Silver was enriched by over 50-fold in ovaries. The results suggest that low concentrations of some metals in muscle of adult female goldeye, relative to concentrations in female juveniles and ovaries, may be maintained in part by transfer of metals to the external environment in eggs at spawning (Donald and Sardella, 2010). Parameters sampled are listed in Appendix 1.

Polycyclic aromatic hydrocarbons have been identified as an environmental concern in the surface-mineable oil sands region. Environmental data collected by RAMP and government agencies were analyzed by Timoney and Lee (2011) to determine whether the concentration of sediment PAHs in the Athabasca River Delta changed through time. Total PAH concentrations in the sediment of the Athabasca River Delta were found to increase between 1999 and 2009. Annual bitumen production and mined sand volume, extent of landscape disturbance, and particulate emissions were correlated with sediment PAH concentrations as were total organic carbon in sediment and discharge of the Clearwater River, a major tributary of the Athabasca River. Among four tributaries of the Athabasca River, only the Clearwater River showed a significant correlation between discharge and sediment PAH concentration at their river mouths. (Timoney and Lee, 2011).

Two studies by Kelly *et al.* (2009, 2010) on polycyclic aromatic compounds (PACs) and 13 metals revealed that oil sands developments had a previously underestimated pathway of contamination. Loading to snowpack from airborne particulates was a significant source of PAC and metals. Bitumen upgraders and local oil sands development were considered key sources of airborne emissions. In the Athabasca and its tributaries, development within the past 2 years was related to elevated dissolved PAC concentrations. In snowpack, metals (excluding selenium) were greater near oil sands developments than at more remote sites. Concentrations of metals and PAC in tributary watersheds tended to be greater near disturbed areas. At sites downstream of development and within the Athabasca Delta, concentrations of 11 metals were greater than upstream of development (Kelly *et al.*, 2009, 2010). Parameters sampled for these two studies are listed in Appendix 1.

Sokal *et al.*, (2010) monitored water chemistry, macrophyte biomass and planktonic diatom communities seasonally over 3 years (2003–2005) from six lakes of the Slave River Delta. Results indicated that river flooding was the dominant hydrological process controlling the physical and chemical conditions, planktonic diatom communities and macrophyte biomass in lakes of the Slave River Delta. In the absence of river flooding, lakes had relatively high

concentrations of nutrients and low concentrations of most ions, but when flooded, concentrations of nutrients decreased and ions increased. The physical and chemical conditions in frequently flooded and non-flooded lakes were relatively stable from year to year, whereas lakes that were intermittently flooded fluctuated widely depending on whether or not a flood had occurred. River flooding also reduced water transparency, which decreased macrophyte biomass. Lakes that did not flood had higher macrophyte biomass and clear waters (Sokal *et al.*, 2010). Water quality parameters sampled in this study are listed in Appendix 1.

A3: REGULATORY ASPECTS

A3.1: Environmental Effects Monitoring

Environmental Effects Monitoring (EEM) is a science-based tool specifically developed for use in Fisheries Act regulations, to determine if effects occur in the receiving environment (exposure area) of regulated facilities. EEM can detect and measure changes in aquatic ecosystems (i.e., receiving environments) potentially affected by human activity (i.e., effluent discharges). EEM is an iterative system of monitoring and interpretation phases that can be used to help assess the effectiveness of environmental management measures. While EEM is presently employed within a regulatory context in Canada, the concepts and approaches are applicable to other types of environmental assessment (both regulatory and non-regulatory). EEM can be used as an assessment tool to help determine the sustainability of human activities on ecosystem health. EEM is a requirement for regulated mills and mines under the Pulp and Paper Effluent Regulations (PPER) and the Metal Mining Effluent Regulations (MMER), both under the authority of the Fisheries Act (Lowell *et al.*, 2005). Pulp and Paper Effluent Regulations (PPER) can be found at:

(http://laws.justice.gc.ca/en/showtdm/cr/SOR-92-269//?showtoc=&instrumentnumber=SOR-92-269).

Metal Mining Effluent Regulations (MMER) can be found at:

http://laws-lois.justice.gc.ca/eng/regulations/SOR-2002-222/index.html

EEM is a science-based performance measurement tool used to evaluate the adequacy of these regulations in protecting fish, fish habitats and the use of fisheries resources. The pulp and paper and metal mining industries are required to meet their regulatory requirements, which include conducting:

- water quality studies;
- effluent characterization studies;
- sublethal toxicity testing; and
- biological monitoring studies in the receiving environment.

These biological monitoring studies and chemical/toxicological analyses are conducted by the regulated industries to assess and investigate the effects caused by their effluent discharges Environmental Effects Monitoring website).

A definition of effect is required to tier the EEM program. Definitions of effects on fish, fish tissue and benthic invertebrate community are laid out within the PPER and MMER. Essentially, an effect is a statistically significant difference in fish or benthic invertebrate community indicators

taken in an exposure area and reference area (or along a gradient of effluent exposure), or an exceedence of the Health Canada tissue guidelines in fish exposed to the effluent (Environmental Effects Monitoring website).

There are 4 pulp and paper mills that conduct EEM on the main stem of the Athabasca, one on the Lesser Slave River (Athabasca watershed), one on the Peace and one on the Wapiti. (7 total in Alberta) (Paula Siwik, Environment Canada, EEM coordinator, pers. comm.).

In British Columbia, on the Peace River drainage, the Kemess South copper/gold mine performs EEM on first order (i.e., small) creeks near the headwater of the Findlay River, which enters the north end of Williston Reservoir. The pulp and paper EEM sites for the Mackenzie mill are on Williston Reservoir. There is also a pulp mill at Taylor, which discharges to the Peace River immediately south of Fort St. John (Mike Hagen, Environment Canada, EEM coordinator, pers. comm.).

Figure 11 shows the facilities subject to EEM requirements under the PPER or MMER in the Peace and Athabasca River systems. Parameters measured are included in Appendix 1. While these operations tend to be far upstream of the Expanded Geographic Extent area, fish, benthic invertebrate and water quality data collected by pulp and paper mills under the PPER EEM requirements could potentially be used as geographic and/or temporal reference data, in comparison to monitoring data from the oil sands monitoring program. This concept was also suggested in Lott and Jones (2010). The concepts and approaches of EEM are also relevant to the design and application of many monitoring programs.

A3.2: Alberta Water Act, and Environmental Protection and Enhancement Act

The purpose of an Environmental Protection and Enhancement Act (EPEA) Approval is to support and promote the protection, enhancement and wise use of the environment. Schedule 1 of the Activities Designation Regulation specifies activities that require Environmental Protection and Enhancement Act Approvals. Some examples of activities designated under these regulations as requiring an approval include: sour gas plants, wastewater management and potable water systems, brine storage ponds, hydrostatic test water releases, sulphur storage facilities, sulphur manufacturing or processing plants, syngas plants, power plants, transmission pipelines, and oil sands processing plants. General provisions of the Environmental Protection and Enhancement Act also apply (Alberta Energy Resources Conservation Board website).

Key stressors for the Peace and Athabasca River basins were summarized in the NRBS Synthesis Report 11 on cumulative impacts (Wrona *et al.*, 1996). Major point source effluent discharges were identified in the NRBS Synthesis Report 3, on distribution of contaminants in the Peace, Athabasca and Slave River basins (Carey *et al.*, 1997). The location, treatment technology and waste disposal methods of all licensed municipal and other (excluding pulp and paper mills) effluent dischargers in the Peace, Athabasca and Slave River basins were summarized for the NRBS program by SENTAR Consultants Ltd. (1996). Some of this information may be out of date, and an updated summary of EPEA licensing information may be needed. A comprehensive update of the NRBS database of effluent licenses created by SENTAR is beyond the scope of this document, however, it is important to note that EPEA information is relevant to examinations of impacts and stressors in the Expanded Geographic Extent.

Approval documents are searchable on the Alberta Environment Approval Viewer webpage at: http://environment.alberta.ca/01519.html

Below is a list of municipal EPEA approvals for water intakes/wastewater outfalls in the Peace and Athabasca Rivers [at the time of this writing]. EPEA records do not show any intakes/outfalls in the Alberta portion of the Slave River (Stephen Yeung, Alberta Environment, pers. comm.). EPEA approvals can be searched and downloaded using the EPEA approval number as provided in the list.

Table 1: Municipal EPEA Approvals for Water Treatment Intakes/Outfalls - Peace, Slave, Athabasca Rivers.

Name of Facility	Facility Type	EPEA Approval #	EPEA Expiry Date (m/dd/yyyy)
PEACE RIVER - SHAFTESBURY	WTR	16517-01-00	31/03/2019
PEACE RIVER - 103RD STREET	WTR	16517-01-00	31/03/2019
PEACE RIVER CORRECTIONAL CENTRE	WTR	17584-01-00	01/08/2018
FORT CHIPEWYAN	WTR	380-01-00	31/03/2020
SMITH	WTR	1166-02-00	01/05/2011
ATHABASCA	WTR	377-02-00	28/02/2017
FORT MCKAY	WTR	685-02-00	01/07/2015
FAIRVIEW	WTR	659-01-00	01/01/2016
FORT VERMILLION (under Mackenzie Region Approval)	WTR	9764-02-00	01/06/2016
FORT MCMURRAY	WTR	690-02-00	01/12/2018
FAIRVIEW RURAL WATER CO-OP	WTR	232862-00-00	Registration
NORTHERN SUNRISE COUNTY	WTR	236138	

The EPEA Industrial Approvals for Water Treatment Plants and Outfalls in the Peace, Athabasca and Slave Rivers are listed below.

Table 2: Industrial EPEA Approvals - Peace, Slave, and Athabasca watersheds.

Name of Facility	Facility Type	EPEA Approval #	Watershed
Daishowa Marubeni International	pulp and paper mill	115	Peace River
Peace River Silica Sand	Quarry	70667	Peace River
Milner Power	power	9814	Smokey River (tributary of the Peace River)
Grande Cache Coal	Coal mine	155804	Smokey River (tributary of the Peace River)
Weyerhaeuser	pulp and paper mill	113	Wapiti River (flows into Smokey River flows into Peace River)
Slave Lake Pulp	pulp mill	108	Lesser Slave River (tributary of the Athabasca River)
Alberta Pacific	Pulp mill	111-02	Athabasca River
Shell Muskeg River Mine	Oil sands mine	20809-01-00	Athabasca River
Shell Jackpine Mine	Oil sands mine	153125-00-00	Athabasca River
Suncor Energy	Oil Sands Processing Plant and Mine	94-02-00	Athabasca River
Syncrude Mildred Lake, Aurora North, Aurora South	Oil Sands Processing Plants and Mines	26-02-00	Athabasca River

Further details on EPEA approvals for oil sands mine operations in the surface-mineable oil sands area near Fort McMurray, including parameters sampled [at the time of writing], can be found in the Phase 1 Component 2 document (Lindeman *et al.*, 2011). EPEA approvals are regularly updated, and may change over time.

B: MAJOR HISTORICAL RESEARCH PROGRAMS AND FOCUSSED STUDIES

B1: ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM (AOSERP)

The Alberta Oil Sands Environmental Research Program (AOSERP) was a program established by an agreement between the governments of Alberta and Canada in February 1975 (amended September 1977). This program ran from 1975 to 1980, amassing a large amount of baseline information. AOSERP's general objectives were the definition of baseline states and detection of changes that might be caused by the development of the Athabasca oil sands (Smith, 1981).

Under the regional surface water quality monitoring program, the standardization of sampling sites, procedures, and analysis received significant attention. Documentation of the locations of water quality sampling sites, sampling, analytical, and quality control methods used, the volume and availability of assembled data, and a comprehensive appraisal of the quality of the database can be found in Akena (1980).

The AOSERP program included a number of areas of investigation. Atmospheric research culminated in the construction of an air quality model for the region. The land system work established a database for soils and surficial geology, vegetation and wildlife. Water system projects developed baseline information on hydrology, hydrogeology, water quality and aquatic biota. Studies of water chemistry and aquatic biota in the Athabasca River did not reveal significant impacts at that time downstream of Fort McMurray and the two operating oil sands plants, either from the industrial operations or municipal sewage and drainage from the town. Human System research described conditions in the Athabasca oil sands region in historical and contemporary terms. Recommendations for future research were made. The overall assessment of the program concluded that effects of oil sands development were assessed, but not in an integrated fashion. Interdisciplinary connections were lacking, and this was considered a major deficiency of AOSERP research results (Smith, 1981).

Many of the AOSERP studies were conducted within the surface-mineable deposit north of Fort McMurray. The APSERP study area was the Athabasca drainage basin from just upstream of what is now the Grand Rapids Wildland Provincial Park, to the Athabasca Delta and its outlet into Lake Athabasca. The study area did not include Lakes Claire or Mamawi, or other parts of the Peace-Athabasca Delta, but did include Fort Chipewyan and a small area to the north of it. The AOSERP Study Area stopped at the boundaries of Wood Buffalo National Park, and did not include any of the Park lands. A number of the fish and invertebrate studies that did not extend their sampling down into the Athabasca Delta are included here for their historical importance.

B1.1: AOSERP Hydrology Studies

Loeppky and Spitzer (1977) noted that in the 1970's, information on the water resources of the AOSERP study area was very limited. With the industrial development of the Athabasca Oil Sands, the limited coverage of hydrologic gauges in the area was gradually increased to 15 by 1975. Hydrometric data for the Alberta Oil Sands Environmental Research Program study area were compiled to December, 1976. All available daily discharge data to the time of writing were included. Also included were annual hydrographs of discharge data, water level information for gauged lakes, stage discharge curves for each stream gauging station, and, where enough data were available, plots of cross- sections, discharge-velocity and discharge-area curves. Some information on water temperature was also included (Loeppky and Spitzer, 1977). This could provide useful hydrologic baseline data for comparison with current conditions.

Neill and Evans (1979) examined the drainage system of the AOSERP study area, including the Athabasca River and tributaries. Roughly 60% of annual runoff in the study area occurred in a 4-month period (April through July). Runoff represented on average only about 20% of the precipitation that fell on the area, the remainder was considered to return to the atmosphere by evaporation and transpiration. Although snowfall constituted only about 30% of precipitation, its proportional contribution to runoff was generally much greater. On the east slopes of the Birch Mountains, runoff from rainfall appeared to be remarkably small. Year to year variations in runoff were considered quite high for many of the tributaries in the study area. The range of Athabasca River annual variations were approximately twofold in the 20-year period examined. Few data were available [at that time] to permit analysis of interactions between surface water and groundwater. Observational well data suggested substantial recharge of groundwater following

snowmelt and rainstorms. Further investigation of the very low natural runoff in some areas, interactions between surface water and groundwater and the relationship of runoff characteristics to basin physiography and vegetal cover were recommended for the future (Neill and Evans, 1979).

Mixing characteristics of the Athabasca River below Fort McMurray under ice-covered flow conditions were studied by Beltaos (1979). Two tracer tests were conducted in February 1978 to provide the necessary field documentation. The results of these tests were analysed using theoretical models from the literature. To model the results of the slug test within the first 20 km from injection, a numerical algorithm was utilized together with the mixing coefficient found from the first test, and shown to give fair predictions. The effects of bars and islands on applications of this algorithm appeared to be of localized nature. It was suggested that such effects could be ignored unless pertinent hydrometric data were available in considerable detail (Beltaos, 1979).

B1.2: AOSERP Water Quality and Sediment Studies

Several water quality studies that were concentrated in or upstream of the surface-mineable oil sands area, but did not extend sampling downstream into the Athabasca Delta or PAD are not included here, but can be found in Lindeman *et al.* (2011).

Akena and Christian (1981) provided an assemblage of non-AOSERP surface water quality data dating back to the 1950s. Most of the data were abstracted from reports of federal and Alberta government departments, Alberta Research Council, universities, oil sands industry, and private consulting firms. Unfortunately, the studies used a wide variety of sample collection, storage, and analysis procedures; and, in a large number of cases, the databases did not contain clear descriptions of the exact locations of sampling sites, consistent sites and parameters monitored, documentations of the sampling procedures, sample preservatives, analytical methods, detection limits, or precision, or indications of the quantity, quality, or accuracy of the data base. Despite these drawbacks, the compilation of surface water quality data could be used to supplement the AOSERP surface water quality database, especially in areas where, or on occasions when, AOSERP data were not collected (Akena and Christian, 1981).

Allan and Jackson (1978) collected and analyzed dredged sediments and sediment cores from sites along the Athabasca River system from between Fort McMurray and the confluence of Rivière des Rochers with the Slave River. A selected sample suite representing all of the drainage units and textural variations was analysed by several total and partial element extraction techniques. The results indicated that total concentrations were low when compared to data for natural and for polluted sediments elsewhere [at that time]. Concentration variations were strongly affected by sedimentological parameters including sediment texture, Fe/Mn mineral coatings, and organic and carbonate contents. There was a general progression to higher concentrations of heavy metals from the Athabasca River to its delta to Lake Athabasca. The highest heavy metal concentrations were found in the fine textured sediments from Lake Athabasca (Allan and Jackson, 1978).

In a summary report by Corkum (1985), routine parameters, nutrients, and metals were presented for sampling sites along the Athabasca River to detect longitudinal and seasonal changes in water quality and to determine the effect of point source effluents on the river. Changes in ion concentrations on the Athabasca River were attributed to inputs from the Clearwater River rather than industrial saline discharge via Poplar Creek. It was considered that the downstream effect of the Fort McMurray sewage treatment plant was only detectable to the mouth of the Muskeg River. Elevated concentrations of nickel and vanadium occurred during high flow periods, and were interpreted as weathering of natural bitumen rather than with industrial effluents. Principal

component analysis (PCA) was used to analyze selected water quality parameters on the Athabasca River. Sites exhibiting similar water quality characteristics were indicated by cluster analysis dendrograms and delineated on schematic maps of the river. Baseline data and relationships among parameters were presented for east, west, and south drainages entering the Athabasca River between Fort McMurray and Embarras Airport, as well as the Athabasca Delta drainage. An overall analysis of the four regions was conducted using PCA to delineate those sites with similar water quality characteristics, and groupings frequently reflected the geological type of the region (Corkum, 1985). See figure 12 for a map of these sites.

Neill *et al.* (1981) examined circulation of water and sediment in the Athabasca River Delta. The objective of the study was to describe how water and sediment from the Athabasca River were distributed through the delta system and how they circulated and mixed in Lake Athabasca and flowed through to the Slave River, with a view to understanding the pathways and destinations of contaminants that might reach the Athabasca River. Literature reviews, remote sensing interpretations, field investigations and mathematical analyses were included. The hydrology of principal lakes and channels in the study area was summarized, mainly using information from past studies. A series of satellite images and high-level aerial photographs taken between 1973 and 1978 was examined for relevant information on circulation and mixing. A small amount of previous water quality information was analyzed to supplement the remote sensing information. Three field investigations were conducted in September 1979, March 1980 and June 1980. Data collected included water depths, velocities, water quality parameters, and sediment concentrations. A special study of dispersive mixing was conducted during the June 1980 investigation. Field data were compared against satellite data from an overpass about 9 days later. Other information included calculations of jet characteristics from delta inflows, estimates of the zone of influence of lake outflows, and a consideration of the potential for mathematical and physical modelling of the system (Neill *et al.*, 1981).

Hesslein (1979) surveyed twenty lakes in the AOSERP study area in October 1976 to determine their susceptibility to pH change from atmospheric acid additions. Major element chemistry and nutrient concentrations were measured in the water and suspended particulates. Models using the survey information were presented for prediction of pH change in these lakes under various acid loading rates. Most of the lakes in the region had high alkalinities and high resistance to pH change. The only lakes which were considered potentially susceptible to serious pH alteration under high acid load were those in the Birch Mountain area. The simple steady state model suggested that even the more poorly buffered lakes sampled in the Birch Mountain region would only be seriously affected if the pH of rain averaged below 4.0, which was considered unlikely (Hesslein, 1979).

B1.3: AOSERP Fish Studies

A study was undertaken by Lutz and Hendzel (1976) to determine background levels of contaminants in aquatic fauna, water, and sediments in the AOSERP study area. It was hypothesized that metals and organics would be likely to increase in concentration in the areas affected by oil sands operations, leading to increases of those parameters in fish and invertebrate tissue. Establishment of pre-development levels of contaminants in these tissues was considered important to defining the aquatic effects of oil sands development in future. Five hundred sixty fish (of 8 species), 15 water samples, 14 sediment samples and a few phytoplankton and invertebrate samples were analyzed for up to 12 metals and 4 pesticides with PCBs, of aquatic environment samples from 15 study sites along or near the Athabasca River from Fort McMurray north to the confluence of the Peace and Slave Rivers. Fifteen areas along the Athabasca River were chosen as collecting sites; subdivided into northern section, stations 1-5 and southern section, stations 7-16 (there was no station 6) (see Figure 13). Fish, water, and sediments were

collected from each site, and some plankton and benthos were also collected. Results of analyses in each type of sample were presented, according to the detection limits available [at that time]. Parameters such as mercury and selenium were not considered high in fish tissue analyzed. Water samples were noted to have relatively high values of some metals, such as iron and manganese, in particulate form. Sediments were also found to be rich in those same metals (Lutz and Hendzel, 1976).

While not falling within the Expanded Geographic Extent, the following study is included here for its historical significance. Tripp and Tsui (1980) presented the results of work conducted from May to October 1978 on tributary streams in the southern portion of the AOSERP study area [upstream of surface mining, but potentially affected by *in situ* mining operations]. Most of the effort was concentrated on the Christina, Gregoire, and Hangingstone. Other water bodies were sampled once only during late summer. Individual streams were described with regard to habitat categories and the physical characteristics measured at each station. The species composition, distribution, and relative abundance of fish collected in the southern portion of the AOSERP study area were described and compared with previous studies in the AOSERP study area. Life histories of six major species, including Arctic grayling, goldeye, northern pike, longnose sucker, white sucker, and walleye, were described. Discussion of other fish species captured was restricted primarily to their distribution and relative abundance. Several small streams were found to be major spawning and rearing areas for Arctic grayling, including most of Surmont Creek, a tributary of Gregoire Lake, and the lower halves of Saline and Saprae creeks, tributaries of the Hangingstone and Clearwater rivers (Tripp and Tsui, 1980). Raw fish data were presented in a second volume of the study, which at the time of this writing had not been obtained. This could provide useful information to compare against current monitoring and research.

Bond (1980) sampled the fish populations of the Athabasca River downstream of Fort McMurray during the open-water period in 1976 and 1977. Fish were collected with gillnets, seines, and angling gear in order to identify the species present, to document their distribution and relative abundance, and to obtain samples for life history analysis, and some nine thousand fish of the major species were tagged. Twenty-seven fish species were identified from the Athabasca River, 11 of which were common. Species diversity was greatest near Fort McMurray, where all 27 species occurred, but decreased downstream, with only 18 species captured in the Delta study area. Major upstream spawning migrations, initiated under ice-cover, of walleye, goldeye, longnose suckers, and white suckers occurred in the Athabasca River during early spring. Gradual downstream dispersal occurred after the spawning runs, and continued throughout the summer. The entire lower Athabasca River apparently served as a summer feeding area for immature goldeye, which entered the study area prior to break-up and left in late autumn. A large upstream spawning migration of lake whitefish occurred during September and October. Some whitefish returned to Lake Athabasca shortly after spawning but others were considered to overwinter in the Athabasca River. Troutperch, flathead chub, emerald shiners, lake chub, and spottail shiners were the major forage fishes in the study area. Tagging study results suggested that walleye, goldeye, lake whitefish, longnose suckers, and white suckers found in the lower Athabasca River belonged to populations that overwintered in Lake Athabasca and the Peace-Athabasca Delta (Bond, 1980).

Kristensen *et al.* (1975) investigated walleye in the Richardson Lake-Lake Athabasca system, goldeye in the Lake Claire-Mamawi Lake system, and made field observations of the Little Rapids weir on Rivière des Rochers. Baseline conditions with respect to walleye and goldeye in the Peace-Athabasca Delta included spawning success, movement, distribution, age structure, and several other biological characteristics. The study provided baseline information on walleye and goldeye populations relevant to increasing levels of oil sands development, but also in the context of conditions produced by remedial measures implemented after the Peace-Athabasca Delta Project investigations into the effects of the Bennett Dam constructed on the Peace River in 1968. Richardson Lake was found to be a major spawning ground for walleye and spawning in

Richardson Lake was considered to provide most of the annual recruitment to the Lake Athabasca walleye population. Due lack of flowing water under the ice, it was thought that walleye could not enter Richardson Lake until flood waters from the Athabasca River flowed into Richardson Lake via Jackfish Creek, demonstrating the vulnerability of this spawning run to unusually low water levels in spring. A large number of goldeye gillnetted at Little Rapids suggested that Rivière des Rochers is an important migratory route for goldeye in and out of the Delta. The distribution of goldeye fry was thought to be correlated with type of shoreline vegetation (Kristensen *et al.*, 1975).

Sekerak and Walder (1980) studied the physical characteristics of nine streams within five watersheds (Firebag, Muskeg, Steepbank, MacKay, and Ells) in the AOSERP study area. The distributions and relative abundances of fish in each stream and watershed were related to physical characteristics. Detailed results were presented in an atlas that formed Volume II [unavailable at time of writing]. From 16 to 24 species of fish were found in each watershed. Forage fish (lake chub, pearl dace, longnose dace, trout-perch, brook stickleback, slimy sculpin) and white and longnose suckers were the most abundant fish in all watercourses studied. The most important and widespread sport fish present were (in order of decreasing abundance) arctic grayling, northern pike, and walleye. Other species of sport fish (burbot, lake whitefish, mountain whitefish, yellow perch, Dolly Varden, and goldeye) were found in small numbers, and were almost always confined to the lower reaches of the rivers in proximity to the Athabasca River. A good correlation was found between physical characteristics of streams and the distributions and abundances of fish (Sekerak and Walder, 1980).

B1.4: AOSERP Invertebrate Studies

A number of the AOSERP invertebrate studies were done in the surface-mineable oil sands area, and did not extend into the Expanded Geographic Extent, which is the focus of this report. However, available AOSERP invertebrate reports are summarized here because of their historical significance. AOSERP studies that were not available at this writing may include further valuable historic information.

Invertebrate and biofilm fauna of the Athabasca River and the Muskeg and Steepbank tributaries were studied by Barton and Wallace (1980). Distinctive faunal communities could be distinguished on limestone rubble, glacial till, muskeg reaches, brooks, and oil sand. The variety and density of invertebrates on oil sand were significantly less than on rubble substrates. Flooding of riffle habitats reduced benthic standing stocks, which recovered rapidly with resumption of normal flow. Benthic communities in the Athabasca River were strongly influenced by substrate. Changes in texture of sediments and the number and variety of organisms appeared to be directly linked to variations in the direction and magnitude of river flow as discharge fluctuated, and to life histories of invertebrate species. Autumn quantitative estimates of standing stocks of microbenthos on bedrock and macrobenthos on the entire range of sediments in the Athabasca River were obtained. The unstable sand which covered most of the mainstem riverbed supported large numbers of a few specialized chironomids. Other studies were conducted on the responses of freshwater bacterial, algal and macroinvertebrate communities to contamination of substrates by oils. Oil contamination produced substantial changes in the colonization of bare stone surfaces by aquatic organisms but no great shifts in community structure of established epilithic biota. Suspended and epilithic communities of the Muskeg and Steepbank rivers were found to biodegrade the saturate fraction of synthetic crude oil at 20°C and more slowly at 4°C. Materials which could be used in the reclamation or diversion of streams, ranging from tailings sand to large cobbles, were compared for the nature of the macrobenthic communities which became established. Limestone gravel for riffles and overburden for slow reaches appeared to provide for nearly natural biological productivity (Barton

and Wallace, 1980). These data may be of use in future examinations of development impacts and mitigation approaches.

Crowther and Lade (1980) assessed the level of secondary production in the Muskeg River. A trophic rather than a, taxonomic approach to aquatic invertebrate classification was taken and a modification of the Hynes method was used for the calculation of production. It was found that secondary production in the Muskeg River was highest upstream by a factor of two times that of a central site and four times that of a downstream site. The data also showed that the trophic economy of upstream sections of the river was based upon detrital and algal feeding and their importance decreased in a downstream direction, whereas the importance of carnivores and omnivores increased in a downstream direction. This was based upon the availability of coarse particulate organic matter (CPOM) at upstream sites, which was degraded to fine particulate (FPOM) and refractory particulate organic matter (RPOM) and exported downstream (Crowther and Lade, 1980).

In a study by Hartland-Rowe *et al.* (1979), Hartley Creek [now commonly referred to as Jackpine Creek] benthic fauna was found to be dominated numerically by Chironomidae but by Trichoptera in biomass. Four substrate types found in pools each had a distinctly different benthic community, and riffle benthic communities were different from those of pools. A "single-rock" sampling technique showed that the microdistribution of trichopteran larvae was influenced by both rock size and the presence or absence of moss cover. Most of the aquatic insects were univoltine (producing only one brood per year), with spring or summer emergence, although a few species (some Chironomidae and Baetinae) may have been multivoltine. Invertebrate drift displayed a typical diel cycle with morning and evening peaks. Predominant benthic components included Baetinae and Chironomidae but Cladocera and Copepoda were also abundant in pools and drift. Temperature and discharge profoundly affected structure and composition of benthic communities but none of the chemical factors measured appeared to be a significant influence (Hartland-Rowe *et al.*, 1979). Hartley Creek is now commonly referred to as Jackpine Creek in Environmental Impact Assessments, RAMP reports and local maps, although the Atlas of Canada still labels it Hartley Creek.

The study by Tripp and Tsui (1980) in the southern portion of the AOSERP study area, although mainly aimed at fish, also included habitat and invertebrate work. Seasonal and longitudinal variations in benthic species composition, abundance, distribution, community structure, standing crop, and invertebrate drift were discussed in detail for the Hangingstone and Christina rivers. Similar data, for late summer only, were presented for other water bodies sampled during the study. Eighty percent of the streams were dominated by aquatic insects, with only 20% dominated by molluscs. Among the aquatic insects, Ephemeroptera, Diptera, and Trichoptera were the three most common and abundant orders. Both diversity and standing crop of the macrobenthic community appeared to be lowest during June. Species diversity appeared to be highest during August, while standing crops reached peak levels either in the summer (e.g., the Christina River) or in the autumn (e.g., the Hangingstone River). Species diversity and the average number of taxa present were generally highest on boulder, rubble, or gravel substrates, and lowest in areas of muskeg or sandy substrates. The mean density of benthic invertebrates appeared to be related more to longitudinal factors rather than the substrate characteristics of each stream habitat category (Tripp and Tsui, 1980). The raw invertebrate data were contained in a second volume, which was not obtained as of this writing.

B2: DELTA STUDIES SERIES

Concerns over potential changes to the hydrology of the Athabasca and Peace Rivers and downstream Peace-Athabasca Delta (PAD) as a result of human development and climate

variability/change led to a number of research initiatives involving Environment Canada over the last 40 years: the Peace-Athabasca Delta Project Group (PAD-PG, 1973), Peace-Athabasca Delta Implementation Committee (PAD-IC, 1987), and Peace-Athabasca Delta Technical Studies (PAD-TS, 1996). The Northern River Basins Study (see section B3, below) ran concurrently with PAD-TS.

B2.1: The Peace-Athabasca Delta Project Group (PADPG)

In answer to concerns around low water levels being experienced in the Peace-Athabasca Delta, the governments of Canada, Alberta and Saskatchewan established a Peace-Athabasca Delta Project Group (PADPG) to conduct a detailed investigation into the problem of low water levels in Lake Athabasca, their cause and effect on the delta and upon local people. Priority was placed on determining an immediate solution to restore water levels, if only temporarily, in the spring of 1972, and then also on developing a long-term solution. In the fall of 1971, a temporary rock fill dam was constructed on the Quatre Fourches River at Dog Camp to improve water levels in a major part of the delta. Another project that was completed during the PADPG was a meander cut-off on the Athabasca River, to prevent it from joining with the Embarras River. A detailed assessment was made of all aspects of the ecosystem, including hydrology, ecology and the impact of changes on local people. It was concluded that there were immediate impacts of Bennett Dam operation due to the reservoir filling phase, and that impacts would continue into the future on the Peace River due to on-going operation of the dam. Among other recommendations for on-going management and monitoring of the delta, the PADPG recommended (1) construction of a submerged weir control structure at Little Rapids on the Rivière des Rochers to restore levels on Lake Athabasca and consequently on the delta, and (2) the subsequent removal of the temporary rock fill dam (Peace-Athabasca Delta Project Group, 1973).

B2.2: Peace-Athabasca Delta Implementation Committee (PADIC)

Peace-Athabasca Delta Implementation Committee (PADIC) was an intergovernmental committee, again representing the governments of Canada, Alberta and Saskatchewan, established in 1974 to coordinate programs related to restoring low water levels that had occurred in the delta following construction of the W.A.C. Bennett Dam on the Peace River and filling of the Williston Reservoir in 1968-71. Under PADIC, two rock fill weirs were constructed on the Rivière des Rochers and Revillon Coupé to delay the rate of outflow and raise water levels throughout the delta. PADIC also studied the natural diversion of water into the delta from the Athabasca River via the Embarras River breakthrough to Mamawi Creek, and became involved in remedial measures for the Rivière des Rochers site by upgrading the boat tramway and evaluating the need for a fishway (Peace-Athabasca Delta Implementation Committee, 1987).

B2.3: Peace-Athabasca Delta Technical Studies (PADTC)

The Peace-Athabasca Delta Technical Studies were a three-year program of research, 1993-1996, intended to be a companion to the Northern River Basins Study. The objective was to improve understanding of the effects of Peace River flow regulation and climate variability on the delta's hydrology, and to assess potential remediation options for restoring the role of water. The scope was to review and assess existing information, fill information gaps and test remediation options. The results were intended to form the basis of a PAD Management Plan. Partners included Canada, Alberta, BC Hydro, Mikisew Cree First Nation, Athabasca Chipewyan First

Nation, and the Fort Chipewyan Métis Association (Peace-Athabasca Delta Technical Studies, 1996).

The program was comprised of a number of individual studies:

- "Understanding the Ecosystem" investigated delta hydrology and how it had been affected by flow regulation and climate variability. The historical role and relative importance of spring ice-jams to the flood regime of the delta, the conditions required for the occurrence of ice-jams, the relative influence of flow regulation and climate variability and nature and role of flood water flow across the delta required further investigation. Component studies included a flood history study, ice studies, the Embarras River breakthrough, topographic database, hydrodynamic model, a digital elevation model, perched basin water balance model, and vegetation model.
- "Water Management Options" investigated techniques for managing water in the delta. Component studies included artificial ice strategies, structural alternatives, and alternative remediation.
- "Monitoring the Ecosystem" developed programs to establish a baseline of ecosystem conditions against which ecosystem management objectives could be evaluated. Component studies included a vegetation monitoring program, and remote sensing (Peace-Athabasca Delta Technical Studies, 1996).

Major findings of the program included the following:

- Both spring and summer floods played important roles in the ecology of the delta. Spring break-up ice-jams on the Peace and Athabasca Rivers were required to generate water levels capable of flooding the isolated perched basins. Summer high water events and low winter flows on these rivers created water level fluctuations on the delta's large lakes and connected channels that maintained productive near-shore habitats.
- The frequency of significant spring flooding of the delta decreased after regulation of the Peace River by the W.A.C. Bennett Dam. Influences of both regulation and climatic variability impacts affected the occurrence of Peace River ice-jams.
- Winter releases from the Bennett Dam created higher elevation ice cover and increased Peace River flows through winter to break-up. More tributary run-off during spring was required to generate dynamic break-up events and flooding near the delta (regulation effect). However, since the mid-1970s, declining snowpack levels in tributary headwaters downstream of the dam reduced the amount of available spring run-off (climate effect).
- Regardless of future variations in climate, regulation effects on ice-jamming were expected to persist under the normal operating regime of the Bennett Dam.
- The regulation effects could be mitigated by modifying Bennett Dam operations. Reductions in flow releases during freeze-up could create lower ice cover elevations near the delta. Enough cross-sectional area under ice would have to be maintained to accommodate higher mid-winter releases and prevent mid-winter break-ups. Maintaining or increasing flow releases during break-up would complement tributary run-off effects. The timing and magnitude of releases would be constrained by the risk of flooding to communities downstream of the dam.
- The W.A.C. Bennett Dam reduced the peak summer flows on the Peace River, and the amplitude of annual water-level fluctuations on the delta's large lakes and connected channels. Outflow weirs constructed on the Rivière des Rochers and Revillon Coupé nearly restored peak summer water levels in the delta, but raised winter water levels and limited seasonal drawdown. The existing water level regime of Lake Athabasca and the other large lakes was relatively stabilized by regulation effects, compared to the natural situation. The ecological impact of stabilized water levels on near-shore habitat was not evaluated.

- Gated outflow structures, in place of the existing weirs, could be operated to restore the natural range of water levels in Lake Athabasca and the other large lakes and connected channels. These structures would be very expensive and require continual management.
- Further research on the application of recommended water management options, particularly regarding hydraulic and hydrological modeling of the Peace River catchment was called for, as well as a successor organization to the PAD Technical Studies. It was considered that any successor organization should be made up of those authorities with concerns within the Peace-Athabasca Delta, including Parks Canada, Alberta Environmental Protection, the Mikisew Cree First Nation, the Athabasca Chipewyan First Nation, and the Fort Chipewyan Metis Association, with support from BC Hydro and appropriate government agencies (Peace-Athabasca Delta Technical Studies, 1996).

Many reports were generated as these studies progressed. PADTS reports are listed in the Final Report (Peace-Athabasca Delta Technical Studies, 1996). Since many, if not most, were subsequently folded into other reports and publications, they are not itemized here.

B3: NORTHERN RIVER BASINS STUDY (NRBS)

In the late 1980s, northern residents became concerned about the impact of proposed industrial and resource development in the Peace, Athabasca and Slave River basins, particularly new pulp mills and associated forestry operations (Gummer *et al.*, 2000). As a result, the governments of Canada, Alberta and Northwest Territories launched the Northern River Basins Study (NRBS) in 1991. The overall objective study was to assess the cumulative effect of all forms of development on the natural aquatic ecosystem. Broad topics for the scientific questions included water quantity and use, water quality, fisheries and wildlife. Most northern residents wanted to know if it was safe to drink the water and eat fish out of northern rivers. Therefore, a large portion of the funding was directed toward water quality and fish (Northern Rivers Ecosystem Initiative (Canada), 2004).

A primary recommendation by the Environmental Assessment Review Panel for the Alberta Pacific Pulp Mill in 1989 dealt with the importance of cumulative effects (Gummer *et al.*, 2000). NRBS was set up as a 5-year program, with Federal-Provincial-Territorial financial contributions. The program was to adopt a "weight of evidence" approach, and included eight science components: hydrology, nutrients/dissolved oxygen, drinking water, food chain, contaminants, synthesis/modeling, traditional knowledge, and aquatic uses (Gummer *et al.*, 2000). More than 165 peer reviewed studies from field and lab investigations, and 13 synthesis reports were generated from the program.

A database (More *et al.*, 1996) was constructed to contain information about the environmental samples collected and analysed for the NRBS. The database contributed to fulfilling one of the three specific objectives contained in the Northern River Basins Study agreement: "To provide a scientifically sound information base for planning and management of the water and aquatic environment of the study area so as to enable its long-term protection, improvement and wise use." The database contained records identifying 26,780 original samples taken in various media, including liquid, sediment, benthos, fish, mammals, birds and vegetation. The majority of these samples were fish. Fish handled and released (with or without tags) were subtracted out. The database consisted of two major sets of dBASE IV (.DBF) files; one set described the samples and another set provided values for parameters measured (More *et al.*, 1996).

B3.1: NRBS Hydrology and Modelling

A modelling exercise by Aitken and Sapach (1994) assessed the effect of the weirs and Bennett Dam on the Peace-Athabasca Delta water levels during the period 1985 – 1990 using a one-dimensional hydrodynamic model. Previously this had been done up to 1984. The objective was to extend that analysis to 1990. Flow scenarios were modelled to simulate natural (no dam), the effect of the dam, and the dam and weirs (Rivière des Rochers and Revillon Coupé). The modelling results showed that mean and maximum water levels of delta lakes declined due to operation of the dam, while minimum water levels were relatively unaffected. The dam operation raised mean monthly water levels in delta lakes and along river channels in the winter, and lowered them in the summer. Perched basins in the delta required flooding every three to five years to maintain the health of their critical ecosystem. The weirs raised minimum and mean Lake Athabasca and Lake Mamawi water levels significantly above natural conditions and returned the mean and minimum Lake Claire levels to near natural conditions, but with a reduced range of water level fluctuations. The model was limited in that it could not accurately simulate freeze-up and break-up events. Results of this modelling exercise showed changes in water levels at different locations in the delta due to dam operation and could be used to compare flooding frequencies for various parts of the delta (Aitken and Sapach, 1994).

Andres (1996) reviewed and quantified the processes by which an ice cover forms on large rivers. A procedure was developed to forecast freeze-up on a non-regulated river and the derivation of a stability relationship that used both air temperature and discharge to determine whether a juxtaposed or consolidated ice cover would form. The latter was important to characterize the type of ice cover that would occur on the Peace River under regulated conditions. Prior to regulation [by the Bennett dam], at flows of less than 1,000 m^3/s, the river cooled in the fall at the same rate as declining air temperature. A stable ice cover usually formed in early November at Peace Point and in late November or early December at Peace River. After regulation, discharges were two to three times greater. This high discharge of relatively warm water from upstream delayed the time of freeze-up, increased frazil ice, and shortened ice cover duration in the reaches upstream of Fort Vermilion. Only minor effects due to regulation were evident on the freeze-up ice regime downstream of the Vermilion Chutes and at Peace Point (Andres, 1996).

Choles *et al.* (1996) examined background information of the hydrology and processes affecting river flows and lake levels within the mainstem portions of the Peace, Athabasca and Slave Rivers and some of their major tributaries. An annotated bibliography of hydrological information for the study area [at that time] was provided as an appendix. The report concluded that seasonal fluctuations in Lake Athabasca water levels were significantly reduced since flow regulation. Similarly, the mean monthly water levels of Great Slave Lake also changed after flow regulation on the Peace River. A summary of flow and lake level information for water bodies in the Peace, Athabasca and Slave River basins provided a hydrologic background for many of the other reports published by the Northern River Basins Study. Trends in river flows for both the mainstems and significant tributaries, and for lake levels, for both natural and regulated conditions were examined. Ice processes were discussed, along with some of the environmental effects (Choles *et al.*, 1996).

Examination of flow and weather records showed that the historically high open water floods of 1990 did not flood the higher elevations in the PAD. This suggested that open water floods could not produce high enough water elevations, frequently enough, to sustain perched basins. Backwater effects from ice-jams developed during the 1974 break-up were the last documented significant flooding events in the PAD. Records revealed that these ice-jam floods have been attributable to large runoff events in the tributaries, especially the Smoky River, related to large spring snow packs. However, snow packs in the Smoky basin since the mid 1970's were apparently lower than average, which also coincided with the absence of PAD floods. This project

work was a joint venture with a companion study, "Peace Athabasca Delta Technical Study" (Prowse *et al.*, 1996).

Church *et al.* (1997) determined changes in morphology and riparian vegetation in the Alberta reaches of the Peace River by constructing maps of river morphology and principal riparian vegetation communities from air photographs taken at various dates. Field work was undertaken in 1994 to provide ground truth for interpreting the vegetation communities. Maps were completed for 1968 and 1993, so changes that occurred over the 25 years of regulation by the Bennett Dam could be summarised. River morphology was described by water surface, unvegetated bar surface, vegetated bar surface, island surface, floodplain surface, and tributary alluvial fans within the floodplain. Changes during the 25 years since regulation included substantial narrowing of the river in two areas; the reaches from the Alberta border to Dunvegan and Carcajou to Fort Vermilion. Banded galleries of shrubs established on bar surfaces surrounding old island cores. The changes were most extensive in areas with substantial island development where the river had always been least stable. These were places where bed material was transiently stored on its way down the river (Church *et al.*, 1997).

Hicks *et al.* (1996) developed a hydraulic flood routing model of the Peace River between the Bennett Dam, in British Columbia, and Peace Point in Wood Buffalo National Park, Alberta. This model could help evaluate the effects of ice on the propagation of flood hydrographs and extreme events such as dam break floods and surges resulting from ice-jam releases. Only available data (collected by other agencies) were used. Comparisons to actual surveys confirmed that the surveyed river cross sections were well represented by a classical wide, rectangular channel approximation. The final geometric model consisted of more than 1,100 computational nodes describing channel width, effective bed elevation and channel roughness. Although the model was capable of handling highly dynamic flood events (such as dam break floods or surges resulting from ice-jam releases), the test scenarios examined for this preliminary study were simpler "diffusive" waves. It was intended that the model should provide enough information to assess where further surveys are needed, in order to facilitate future tests of this type (Hicks *et al.*, 1996). The Peace River hydraulic flood routing model was updated and extended downstream to include the Slave River. The Slave River model was limited by a lack of tributary data defining contributions from the Athabasca River basin through the Peace-Athabasca Delta. It was concluded that the hydraulic flood routing model, based on limited field data and topographic map data, could reliably predict flood hydrographs. The key advantage of this approach was that output describing flood hydrographs between gauge sites could be produced (Hicks and McKay, 1996).

B3.2: NRBS Water Quality

Numerical models of the transport and fate of environmental chemicals were developed by Golder Associates Ltd. (1997a) for the Athabasca and Wapiti/Smoky Rivers. The models were structured as one-dimensional (longitudinal) models with separate, interacting water column and bed sediment compartments. The models were first calibrated for sodium and total suspended solids (TSS). Organic chemicals, including several pulp-mill related organic contaminants and phenanthrene, were simulated using a set of environmental fate constants developed from a literature search, numerical estimation software and estimation from field data. The results of the initial simulations were compared to observed data and adjustments made to selected fate constants to improve the calibration. The model consistently matched observed dissolved water column concentrations for all chemicals except phenanthrene, but did not provide an adequate simulation of bed sediment concentrations. The simulation results indicated that the most significant model refinement required would be a predictive sediment transport simulation capability, including sediment resuspension (Golder Associates Ltd., 1997a).

Environmental levels of mercury in water, sediment, invertebrates, and fish from the Athabasca, Peace, and Slave River basins were summarized and described in Donald *et al.* (1996a). Data were obtained from existing provincial and federal databases, the Northern Rivers Basins Study, and from government and private sector reports and publications. The review showed that mercury was measured in several hundred water samples from the basins, though was detected in only a handful of samples. Appropriate field and laboratory protocols to sample mercury in water were not used in the past; so most historical detections of this element in water may not have been reliable. The high detection limits used (0.05 to 0.1 µg/kg) were likely why mercury was not detected in most municipal effluents, and only occasionally in industrial effluents (Donald *et al.*, 1996a).

Limnological sampling in the West Basin of Great Slave Lake was conducted by Evans (1997) in March 1994, concurrent with sediment coring studies. Calculations based on the Slave River inflow rate and phosphorus and nitrogen concentrations in its delta channels suggested that the river was a major source of phosphorus and nitrogen to the West Basin, with most of the phosphorus and nitrogen entering the lake during the spring and summer high-flow period. It was estimated that little of the phosphorus and nitrogen entering Great Slave Lake with Slave River inflow was exported from the lake via Mackenzie River outflow. Phytoplankton biomass was low. Diatoms dominated the algal community at sites close to the Slave River mouth. At other study sites, highly motile species were dominant. Algal biomass was greatest offshore of the Slave River mouth and at a site which may have been affected by the Hay River (Evans, 1997).

B3.3: NRBS Sediment

English *et al.* (1996) examined the impact of regulating the Peace River in 1968 on the natural progradation of the Slave River Delta into Great Slave Lake. Changes in the flow regime of the Peace River after impoundment affected the sediment transport regime of the Slave River. Hydrometric data collected by the Water Survey of Canada were used to compare mean monthly discharge of the Peace River at Peace Point with the Slave River at Fitzgerald. Since there were no pre-impoundment sediment data for the Slave River, the mean monthly discharge of the Peace River at Peace Point was used to predict mean monthly sediment load for the Slave River at Fitzgerald (a sediment rating approach). Projections based on this technique indicated a 33% reduction in the average annual sediment load of the Slave River at Fitzgerald in the post dam period. Within this overall reduction, the seasonal distribution of sediment load was changed: sediment load increased 315% during winter, but decreased 46% during the open-water season. Two sets of aerial photographs taken 20 and 18 years apart were examined to compare geomorphological and botanical change in the delta before and after impoundment. Supporting field work was also conducted on the delta from May to July, 1995. The research documented a narrowing in the width of three of the four distributary channels, while a fourth expanded in the period 1946 to 1994. Partial closure of channel entrances and reduction in channel width reduced the capacity of these channels to effectively transport sediment (English *et al.*, 1996).

Bourbonniere *et al.* (1996a and b) studied sediment cores with the goal of identifying significant historical trends in the input of contaminants to Legend Lake, southwest of Lake Athabasca, Weekes Lake to the northeast, and Lake Athabasca itself. Cores were dated by the Pb^{210} method and age-depth relationships were assigned. The depositional environment was determined to have been stable for at least the last 100 years for Weekes Lake but Legend Lake appeared to have experienced a change in sedimentation rate around 1982 (Bourbonniere *et al.*, 1996a). The depositional environment in Lake Athabasca was considered stable for at least the last 100 years. Cores collected from a Lake Athabasca site near the Peace-Athabasca Delta in 1992 and 1993 were analyzed for particle size distribution, bulk C and N species, radionuclides, pulp mill contaminants, heavy metals and mercury, PAHs, aliphatic hydrocarbons and total hydrocarbons,

including petroleum hydrocarbons, fatty acids and biogeochemical markers. Surficial and core results suggested that radionuclides associated with mining activities had been transported away from the point of release, however the levels in the sediment had decreased since the '70s and were approaching background levels. None of the heavy metals tested showed trends except for arsenic, which increased five times over background since the 1970s. The PAHs found were attributed to petroleum and combustion related sources. No clear trends were evident in either of these sources except that the downcore distribution of combustion-related PAHs correlated with a fire frequency curve (since 1932) for Wood Buffalo National Park. Spatially, the distribution of PAHs over the western part of the lake suggested that atmospheric transport was the main control (Bourbonniere *et al.*, 1996b).

Mercury was found in sediment samples from the basins at levels ranging from 27 to 123 µg/kg (dry weight). These levels were well below the draft interim sediment guideline for mercury (170 µg/kg dry weight) that was developed to protect aquatic life. There was no obvious increase in mercury in sediments downstream of industrial effluents compared with sediment at upstream sites. Sediment cores from Lake Athabasca indicated that mercury levels have not increased over at the past 50 years or more, and they also suggested that the Athabasca River basin was the principal source of mercury to Lake Athabasca (Donald *et al.*, 1996a).

Evans *et al.* (1996) collected and analyzed surficial sediments and sediment cores to define the depositional history of sediment-bound contaminants in Great Slave Lake. The cores were dated by the lead (210Pb) and cesium (137Cs) methods. The Slave River was identified as a source of PAHs and the dominant forms were those associated with erosion of oil sands deposits found upstream. Nutrients analysis of the cores suggested that the West Basin of Great Slave Lake had undergone a slight increase in productivity, possibly due to land clearing and increased anthropogenic development in the Peace and Athabasca River watersheds. Localized activities, occurring at the towns of Hay River and Yellowknife, may also have been important. While Great Slave Lake was essentially a pristine system, it did show signs of recent anthropogenic contamination (Evans *et al.*, 1996).

Crosley (1996) examined the results of bottom sediment surveys of the Athabasca and Peace River basins from October 1994 and May 1995. Sediments were analyzed for an array of pulp mill-related contaminants, polyaromatic hydrocarbons (PAHs), chlorinated phenolics, PCBs, extractable organic halides (EOX), toxaphene and mercury. Highest total PAH concentrations were found in the lower basin of the Athabasca River, and in the upstream sites on the Peace River. The highest concentrations of chlorinated phenolics were found downstream of bleached kraft mills in the upper Athabasca River and the Wapiti River. Dioxins and furans were present in low concentrations in bottom sediments of both river basins, and the results did not indicate widespread contamination from pulp mill effluents. No detections were reported for EOX, toxaphene, or total mercury [this is related to available detection limits at that time]. Mean concentrations of some compounds were higher in the sand fraction than the clay-silt fraction of depositional sediment samples. Depositional sediments were found to be an important medium for accumulating several groups of contaminant compounds, but the levels were dropping in most locations (Crosley, 1996).

Results of contaminant analyses were presented for bottom sediments collected from the Peace and Athabasca River basins from 1988-90 by Alberta Environmental Protection and in 1992 by the Northern River Basins Study. No significant correlation was found between contaminant concentrations and percent organic carbon of the fine fraction (the fraction on which contaminant analyses were performed). Organic carbon content of the sediments was a poor predictor of contaminant concentration. Correlations between concentrations of bleached kraft mill-related contaminants were also investigated. There was minimal correlation between the organic content of the samples and the concentration of contaminants. Contaminant concentrations within the sediments were low throughout the river basins (Brownlee *et al.*, 1997).

Dobson *et al.* (1996) tested suspended and bottom sediment samples using four species of freshwater benthic invertebrates in chronic bioassay studies. Measured endpoints were survival, growth (amphipod, chironomid and mayfly) and reproduction (oligochaete worm). Growth and survival of the chironomid was not affected by exposure to the test sediments. The other three invertebrates showed reduced survival, growth and/or reproduction when exposed to bottom sediments from some sites. In the Athabasca River, effects were noted from sediments collected upstream of Hinton, downstream of Whitecourt, downstream of the Alberta-Pacific mill and near the Athabasca delta. In the Smoky River, effects were noted upstream of the mouth of the Wapiti River. In the Peace River, effects were seen upstream of the mouth of the Smoky River. The observed effects of exposure to bottom sediments at these sites may have been due to the combined effects of chemical contaminants (elevated levels of copper and zinc) and physical characteristics (high sand content). Effects could also have been due to other compounds or characteristics not measured in this study. Only the oligochaete worm was exposed to suspended sediments and, although the results were more variable than for bottom sediments, there were few toxic effects on reproduction (Dobson *et al.*, 1996).

Golder Associates Ltd. (1997b) incorporated a sediment transport algorithm for the Athabasca River into the Athabasca River contaminant fate model. The revised fate model allowed predictive sediment transport simulation within the model. The new algorithm allowed the revised model to predict resuspension as well as deposition. Although project results revealed a need for additional work in the area of model parameters and input conditions, the new model better predicted the exchange of sediment between the bed and water column and concluded that they are more dynamic than earlier predicted. The revised model predicted a very dynamic exchange of sediment between the water column and bed, and an accumulation of fine bed sediment over the late fall and winter, removal by resuspension during the spring freshet, and very little net accumulation during the summer. Predicted contaminant concentrations during the winter were similar to the original calibration, however late spring to late fall concentrations were much lower than predicted in the original calibration (Golder Associates Ltd., 1997b).

Carson and Hudson (1997) provided a retrospective review of river processes affecting sediment-associated contaminant dynamics. Sediment fluxes were examined through the use of published material from the Water Survey of Canada suspended sediment monitoring program [see section B5, below]. In addition, the reach-scale mass balance of suspended sediment, and special sediment-associated contaminant flux measurements undertaken for NRBS with centrifuge sampling were examined. Many of the contaminants of concern in the Northern River Basins Study area have a strong affinity to sediment. As a result, the distribution, pathways and fates of many contaminants are closely related to the dynamics of the riverine sediments. The report concludes that while NRBS results have yielded some interesting observations, it would have been most useful for the monitoring and assessment of sediment work to be established prior to any field work being undertaken (Carson and Hudson, 1997).

Figure 14 illustrates the sampling locations for sediments analyzed for metals and PAHs, from the NRBS database.

B3.4: NRBS Fish

Boag and D.A. Westworth and Associates Ltd. (1993) conducted a fisheries survey of the Peace and Slave rivers during spring 1992. Fish species composition, abundance, distribution, and habitat characteristics were determined for thirteen reaches from the Alberta/British Columbia border on the Peace River, to Fort Smith on the Slave River. A total of 29 species were identified during the survey. Forage fish such as minnows, trout-perch, and sculpins dominated the catch. Goldeye was the most abundant sport fish in the Peace River, followed by walleye, burbot,

northern pike, and mountain whitefish (found in the upper reaches of the Peace River only). More fish were caught in the middle and lower reaches of the mainstem Peace River than in the upper reach. Sport fish catch in the Slave River included (in descending order of abundance) northern pike, goldeye, walleye and burbot. Fish abundance in the Slave River was low relative to the Peace River. Overwintering habitat existed throughout the Peace and Slave River mainstems, and the availability of deep water was not a limiting factor in either river. Fish tended to concentrate in snyes, backwaters and tributary confluences, out of the main force of the current. This was especially true for the Slave River where fish were distributed principally within tributaries sampled (Boag and D.A. Westworth and Associates Ltd., 1993).

Balagus *et al.* (1993) documented fish quality in the subsistence winter fishery on the Peace-Athabasca Delta. Whole fish samples were collected from the traditional winter fishing sites in the Peace-Athabasca Delta and Lake Athabasca. The Aboriginal fishermen indicated that winter fishing for human consumption typically occurred when the ice is first thick enough for travel (early to mid-December), rather than the late-winter sampling performed for this study. Although nets can be set throughout the winter, most fish caught in late winter were traditionally used for feeding sled dogs. Northern pike, walleye and lake whitefish were the preferred eating species during the winter months, although goldeye, burbot and white suckers could be eaten depending on need, availability, size of fish and individual preference (Balagus *et al.*, 1993).

Smithson (1993) reported the results of tissue analysis on fish from two traditional winter harvest sites, Hook Point and Bustard Island, at the west end of Lake Athabasca in 1993. The fish were submitted to the Saskatchewan Research Council for radiochemical analysis of muscle and bone. Most of the results for lead-210, polonium-210, radium-226 and thorium isotopes were near or below the detection limit. Uranium was the only radioisotope that exhibited mean concentrations slightly above the detection limits and only the whitefish values were significantly above detection limits. These results are consistent with radionuclide levels reported for fish from other lakes in northern Saskatchewan that are not exposed to uranium mine-mill operations. These results suggested that fish from traditional winter harvest sites at the west end of Lake Athabasca were not contaminated with radionuclides (Smithson, 1993).

Jacobson and Boag (1995) described fish collections from 23 sites in the Peace, Athabasca and Slave River drainages, in 1994. In the Athabasca River drainage, five Athabasca River mainstem sites, and tributaries including the McLeod River, Pembina River, Lesser Slave River, and Clearwater River were sampled. Fish were also collected from the Peace-Athabasca Delta and the Slave River Delta. Burbot, northern pike, longnose sucker, and flathead chub were collected for gross pathological examination. Subsequent studies were to use the samples for contaminant, biochemical, stomach content, and gonad morphology analyses. Most (84%) of the fish examined externally and internally for gross pathological abnormalities and deformities appeared normal. Of the abnormalities observed in 16% of the fish sampled, tumours and lesions of longnose suckers were the most common (Jacobson and Boag, 1995).

A review by Donald *et al.* (1996a) of mercury sampling in fish from the Peace, Athabasca, and Slave River basins revealed that mercury was detected in all fish of every species taken from all lakes and rivers. Mercury levels were highest in predatory fish species such as pike, walleye, burbot, and bull trout and the maximum levels were found in large specimens. For the Athabasca River basin, walleye tended to have the highest mercury concentrations relative to goldeye, northern pike, longnose sucker, and mountain whitefish (in decreasing order). In the reach of the Athabasca River from the town of Athabasca to the southern boundary of Wood Buffalo National Park, 25% of all walleye had mercury concentrations that exceeded the Health Canada limit of 500 µg/kg. From 1977 to 1992, mercury levels had not increased in walleye collected from western Lake Athabasca. Bull trout taken from Williston Reservoir in British Columbia had the highest levels of mercury found in fish collected from all three basins. It was recommended that mercury concentration in walleye from Lake Athabasca and at sites along the lower Athabasca

River downstream from the town of Athabasca should be measured at regular intervals, perhaps every two years (Donald *et al.*, 1996a).

Tallman *et al.* (1996) determined the diet, food web and seasonal changes in structure of the fish community of the lower Slave River in 1994 and 1995. Diet was determined by direct stomach contents examination, and classification of dietary items using the percent occurrence method. Eighteen fish species were collected in the Slave River area. The fish community consisted of highly migratory species (e.g., inconnu and lake whitefish) that spawned in the river in the fall and returned to the lake for most of the year; resident species (e.g., goldeye and flathead chub) that underwent distinct aggregations in the river in the spring, probably for spawning; and resident species such as walleye, northern pike, longnose sucker, white sucker and burbot, that did not show particular aggregations. Based on catch per unit effort, goldeye was the most abundant species. Moderately abundant species included northern pike, walleye, lake whitefish, flathead chub and longnose sucker. White sucker were restricted to the Salt River, a tributary of the Slave River. Inconnu were rare except during the spawning migration. Burbot were also rare, but this may have been due to lower vulnerable to the gear utilized. The piscine food web consisted of specialized, fish-only feeders, such as inconnu and burbot; generalized opportunistic predators such as northern pike and walleye that consume both fish and invertebrates; and invertebrate feeders, such as lake whitefish, goldeye, flathead chub, longnose sucker and white sucker which consume a wide variety of prey items (Tallman *et al.*, 1996).

NRBS frozen tissue collections are held in an archive (Rod Hazewinkel, Alberta Environment, pers. comm.). These constitute a valuable resource for comparative analysis with present and future samples.

Figure 15 shows sampling locations, from the NRBS database, of fish analyzed for metals and PAHs.

B3.5: NRBS Invertebrate Studies

Benthic invertebrate samples obtained from under the ice in late winter 1993 by Dunnigan and Millar (1993) were processed by Saunders and Dratnal (1994). Animals were identified, enumerated, and the wet weight of each taxon was measured. Chironomid larvae parasitized by mermithid nematodes were also enumerated. Ecologically important taxonomic groups were identified to genus level, if adequately developed stages were available. The wet weight per sample for each identified taxon was measured. Mayflies, stoneflies and caddis flies representative of the fauna that was sampled for tissue contaminant analyses by other NRBS studies were identified from five of the nine Athabasca River sites. Results were presented in appendices to the report (Saunders and Dratnal, 1994).

Data on benthic macroinvertebrate community structure for the Peace and Athabasca River systems were compiled by Scrimgeour *et al.* (1995) from a large number of sources, including government and industry. The data sets were used to develop an extensive database of benthic macroinvertebrate community structure, from 1960 to 1992. Marked differences in the sampling techniques used by various studies precluded the use of time series analysis to investigate time-related trends in invertebrate community structure. Instead, invertebrate community classification was compared using cluster analyses of average taxonomic abundance for each community. Results of cluster analyses indicated that benthic invertebrate community structure in the Athabasca River near Hinton and Whitecourt, and in the Wapiti River near Grande Prairie, appeared little affected by municipal and pulp mill effluents (Scrimgeour *et al.*, 1995). Scrimgeour and Chambers (1996) used nutrient diffusing substrates downstream of the Hinton combined effluent to identify the interactive effects of both nutrient enrichment and herbivory (grazing by

aquatic insects) on algal biomass. While outside the scope of the expanded geographic extent, these studies may provide useful data as an upstream reference.

A review of mercury levels in benthic invertebrate samples (Donald *et al.*, 1996a) revealed that mercury was not detected in invertebrate samples collected from the Athabasca River in the Hinton to Whitecourt reach. However, in 1983, in the reach that spanned the Suncor operation, mercury increased in aquatic invertebrates in the downstream direction, from 70 to 1400 µg/kg. This unusually high level in aquatic invertebrates suggested that the Suncor operation in the early 1980s may have been a significant source of mercury to the lower Athabasca River. However, much lower mercury levels in a single sample of invertebrates from 1994 for this same reach implied that the Suncor operation was no longer a major source of mercury. A recommendation of this review suggested that a detailed study should be conducted in the lower Athabasca River to evaluate and identify mechanisms and pathways of mercury uptake by aquatic biota, including an evaluation of the contribution of the waste-water effluent from town of Fort McMurray, and the contribution of the Suncor operation (Donald *et al.*, 1996a).

Long-term data sets measuring benthic macroinvertebrate and fish community structure within the Peace, Athabasca and Slave River systems were collected, and their nature and quality assessed (Cash *et al.*, 1996). Existing databases were compiled into a single standardized and accessible master database (BONAR – The Benthos of Northern Alberta Rivers database). The master database was compiled as a relational database (in Microsoft Access), and was accompanied by a manual explaining its use (Ouellett and Cash, 1995). Information included in the BONAR database, as well as other available historical data on fish and benthic macroinvertebrate community structure collected from within the three basins was analyzed to determine long-term, basin-wide and local effects of human activity (particularly pulp mill activity) on aquatic community structure, and to assess whether data collected within the northern river basins was of sufficient quality and quantity to monitor such effects. It was generally found that available fish community data could not be used effectively as a biomonitoring tool in the northern river basins. Recommendations were provided for the development of a biomonitoring approach that combined rapid assessment protocols and multivariate statistical approaches to biomonitoring, and included characterization of physical, chemical and habitat variables (Cash *et al.*, 1996).

Several other NRBS benthic invertebrate studies strictly associated with upstream pulp mills do not fall within the Expanded Geographic Extent and the findings of these studies are not included here.

NRBS frozen tissue collections are held in an archive (Rod Hazewinkel, Alberta Environment, pers. comm.). These constitute a valuable resource for comparative analysis with present and future samples.

B4: NORTHERN RIVERS ECOSYSTEM INITIATIVE (NREI)

To address the recommendations of the NRBS, as well as the public demand for follow-up studies, the Northern Rivers Ecosystem Initiative (NREI) was set up in 1998. The NREI involved both policy initiatives and scientific research. The five-year study focussed on priorities such as pollution prevention, endocrine disruption in fish, hydrology, contaminants, nutrients, safe drinking water and enhanced environmental monitoring. Its mission was to provide the scientific underpinning to the governments' response to the recommendations of the NRBS (Northern Rivers Ecosystem Initiative (Canada), 2004).

Collectively, these programs examined climate variability/change, land-use change and flow regulation effects on river, delta, and lake hydrology and aquatic ecology upstream of Great Slave

Lake. In particular, NREI included key hydrological studies with a focus on the Athabasca River watershed and delta, including an historical analysis of spatio-temporal streamflow generation to seasonal high flows to the delta (Peters and Prowse, 2006); and hydrological modelling assessment of anticipated effects of future climate change on streamflow generation to the mouth of the river (Toth *et al.*, 2006). These and other relevant hydro-ecological studies were included in a Hydrological Processes Special NREI – Hydrology Issue (Wrona and Gummer, 2006).

B4.1: NREI Hydrology and Modelling

To investigate the relative roles of climate variability and flow regulation, the Peace-Athabasca watershed and delta were modelled using a physically based, distributed hydrologic model and a hydraulic model of the open channel flow system. These models were forced using both historical, station-observed data and climate change scenario temperature and precipitation. A comparison of estimated current and future climate scenarios predicted earlier spring melt and higher winter flows with the annual volume of flows potentially increasing. Warmer temperatures of future climate scenarios and altered flows in the Peace and Athabasca Rivers would influence the timing and growth of ice-jams, the major mechanism by which the Peace-Athabasca Delta (PAD) is hydrologically regenerated. This effect would be compounded by the reduction of flow depth and volume. The modelling showed that, in general, a reduction of winter severity lowered lake levels and river flows. Using the hydrodynamic model, it was estimated that spring river levels would be reduced considerably under climate change. The simulation also predicted lower summer levels in the Peace and Athabasca Rivers (Pietroniro *et al.*, 2004).

A geomatics-based approach for monitoring spatio-temporal changes in the Peace-Athabasca Delta was developed using a combination of Radarsat SAR and visible-infrared satellite images. Generated flood maps for the period between 1996 and 2001 showed the extent of the 1996 and 1997 overland floods and subsequent water level draw down. A spatial flood-duration map based on the flood maps of individual years was also generated, and showed regions in the delta where the frequency of flooding appeared to be highest. General vegetation patterns in the PAD were also mapped using satellite images from summer 2001. Comparisons between vegetation and flood duration maps illustrated the relationship between vegetation patterns and flooding duration. A Digital Elevation Model (DEM) of selected non-flooded areas was created from airborne scanning LiDAR data from the summer of 2000. The DEM was useful for understanding the subtle topographic patterns in this relatively flat region. Comparisons between the vegetation map and the DEM showed that a relationship existed between vegetation patterns and topography. The authors recommended that flood maps and vegetation maps be generated annually to monitor the changes that occur in the delta (Pietroniro and Töyrä, 2004).

Prowse *et al.* (2004) reported on a number of integrated NREI hydro-climatic studies on the Peace-Athabasca-Slave river and lake systems. Historical modelling of the *in situ* water balance of the Peace-Athabasca Delta (PAD) perched basins revealed that these systems were able to retain water for a maximum of 9 years under a wet cycle and as little as 5 years when exposed to relatively steady cool/dry conditions. Further examination of post-regulation ice-jam floods reinforced the findings of earlier NRBS studies that such floods are now primarily generated by "trigger tributaries" (the Smoky River in the Peace Basin and the Clearwater and Pembina sub-basins in the Athabasca Basin). Flows in excess of approximately 4,000 $m^3 s^{-1}$ are required to produce overbank flooding, and major ice-jam floods require intense heating of a snowpack of at least 150 mm water equivalent located in the trigger tributary. Calibration of an ice-jam flood model for the PAD provided for a detailed evaluation of the effectiveness of augmenting flow during the spring break-up period to permit overbank flooding to fill the perched basins in the PAD, confirming an NRBS management recommendation. Additional NREI work focused on the Great Slave Lake and the Slave River Delta. Climate and flow regulation were also found to affect

the water levels of Great Slave Lake, and in turn other near-shore processes, such as wind seiches and ice jamming, that influence flooding, the channel network, sediment deposition and ultimately the biological productivity of the Slave River Delta (Prowse *et al.*, 2004).

B4.2: NREI Water and Sediment Quality

Weins *et al.* (2004) studied the atmospheric contribution of mercury to the aquatic ecosystem in the Athabasca Delta. A year of mercury data monitored at Fort Chipewyan was compared with simultaneous air quality observations in Fort Chipewyan and with mercury measurements at other sites in Canada. Some high mercury events showed an air mass trajectory through the Fort McMurray area, indicating northward transport of aerial mercury (Weins *et al.*, 2004). This work has important implications to the complexity of potential aerial deposition of mercury in the Expanded Geographic Extent.

Research on trace element and organic contaminant deposition by sedimentation in the Slave River Delta (SRD) was undertaken by Milburn and Prowse (1998), with a focus on the temporal and spatial distribution of depositional sediments. Results supported the hypothesis that the under-ice period is a time of significant fine-grained sediment deposition. Contaminant loads in sediment were found to be higher at the end of the winter than in late autumn following the major summer flow events. A comparison of results from this work to other relevant research on the Slave River system shows that the delta is a sink for sediment-bound organic contaminants. Based on the results of this study, the significance of winter should be a major focus of future contaminant surveys (Milburn and Prowse, 1998).

Donald *et al.* (1996b; 2004) discussed the water chemistry of rivers flowing into the Peace-Athabasca Delta, and proposed a series of indicators, including suggestions for specific levels of phosphorus, sulphate, total dissolved solids and dissolved oxygen. Principle components analysis was performed on data for inflowing rivers (the Peace, the Athabasca and the Birch), and on existing data for the Peace-Athabasca Delta, to attempt to identify whether the rivers had distinct chemical characteristics and to determine if sites within the Delta exhibited chemical characteristics attributable to the source rivers. Historic water quality in Lake Claire was most closely matched to the characteristics of the Birch River. More recent data from Mamawi Lake and other Delta sites were more comparable with the Athabasca and Peace River data. Sites in the southern portion of Mamawi Lake overlapped with Athabasca River samples, although other parameters showed non-uniform spatial patterns. It was concluded that the Birch, Peace and Athabasca rivers influence water quality in the Delta, but smaller perched and connected basins also contributed to the chemical characteristics of surface waters. Raw water chemistry data for Mamawi Lake from 1994 and 1999, as well as perched-basin water chemistry data from Ducks Unlimited from 2000, were included in the report as an appendix (Donald *et al.*, 2004).

As part of an assessment of the Canadian Water Quality Guidelines for the Protection of Aquatic Life for dissolved oxygen, Culp *et al.* (2004) investigated the relationship between water column and pore water dissolved oxygen concentrations. One component involved an extensive investigation of water column DO dynamics on the Athabasca River. This component examined the isotopic signature of DO in the water column from near the river's headwaters, upstream of Jasper, and at 22 locations distributed throughout the basin, as far north as Ft. Chipewyan. Water column samples were collected from these reaches over three years, and during several seasons in order to account for winter conditions of low discharge and cold temperature, summer conditions of high discharge and warm temperature, and base flow conditions of low discharge and cool temperature. To establish linkages between physical parameters and processes and associated pore water DO levels, $\delta^{18}O_2$ fractions were examined. Results indicated that the traditionally assumed pore water to water column differential was suspect, because it was poorly

correlated to pore water DO and commonly exceeded the 3 mg/L differential assumed under the guidelines at that time. This finding indicated that the usefulness of water column DO as an indicator for assessing risk in northern rivers was uncertain. Given that low pore water DO was evident even in pristine reference sites, future work must establish the ecological significance of low pore water DO to the sustainability of river biota (Culp *et al.*, 2004).

B4.3: NREI Fish and Invertebrates

Donald *et al.* (2004) also suggested environmental goals for the Peace-Athabasca Delta: maintenance of climate measurements at Fort Chipewyan, water quality, water levels, benthic invertebrate communities, fish community composition, goldeye abundance, and walleye and goldeye commercial catch. Environmentally relevant indicators were selected from the existence of historic information (fish community, water quality), continuous and long-term annual collection of data under other programs (climate, water levels, walleye commercial catch), relevance to the public (water levels, climate, walleye, and goldeye), low cost for determining status (goldeye abundance), and linkages within the food web. Environment Canada, Parks Canada, Alberta Environmental Protection, and the Freshwater Fish Marketing Board collected yearly, agency-specific information on meteorology, water quality, water levels, and the walleye and goldeye commercial catch. These annual records were evaluated for long-term stability or trends. In addition, data were collected in 1994, 1999, and 2002 on the fish community, goldeye abundance, and water quality of Mamawi Lake. It was recommended that all of the annual and specific monitoring and data acquisition programs compiled for this report should be maintained in the future, and a full assessment of the ecological integrity of the aquatic environments of the Peace-Athabasca Delta should be performed once or twice per decade using the indicators identified in the report, and other pertinent information. The clam shrimp *Caenestheriella belfragei* was proposed as a benthic invertebrate Ecosystem Indicator species. However, conchostracan crustaceans are known to have eggs that that can remain in a resting state in sediments for years (Donald *et al.*, 2004). It is now understood that this clam shrimp, as a "boom and bust" population with unknown triggers, would not make a good indicator. Figure 16 shows field component locations for this study.

Environment Canada (2003) commissioned a review and synthesis report of the state of knowledge of the Great Slave Lake aquatic ecosystem. The objectives of this report were to describe Great Slave Lake ecosystem function, determine the key stresses on that ecosystem, and, within the limits of the data, assess the vulnerability of the ecosystem. Stresses or perturbations were primarily considered human activities, but natural occurrences were also considered. A multi-disciplinary team undertook an intensive review of published and unpublished reports and contacted individuals with specific knowledge of the Great Slave Lake area through face-to-face and telephone discussions, primarily held in Yellowknife, Hay River, Edmonton, Saskatoon and Winnipeg. The main external and internal stresses on the system were identified and evaluated with respect to the potential vulnerability of the lake ecosystem. Major information gaps were identified and evaluated. As a result of human activities within the basin, the broader region and globally, a number of stresses upon the Lake were identified. These included:

- emissions and discharges from abandoned and operating mines, of which gold mines in the vicinity of Yellowknife are most notable;
- non-point runoff and sewage discharge from the city of Yellowknife;
- influent rivers transporting nutrients and contaminants, of which the Slave River represents approximately 80% of the total flow;
- atmospheric deposition of nutrients and environmental contaminants including pesticides;
- dam construction within the watershed and resultant effects on hydrology, especially for Slave River;
- population growth and increased tourism;

- effects of climate change including, for example, increased forest fire frequency
- contaminant residues within the lake system derived from long range atmospheric transport and deposition as well as riverine transport;
- commercial gillnet fisheries;
- Aboriginal and non-aboriginal subsistence fisheries; and
- sports or recreational fisheries.

Knowledge gaps and recommendations included the need for new fisheries studies (particularly spawning and rearing areas), water quality monitoring including enhanced efforts on key contaminants, modelling, climate change analysis (including Traditional Ecological Knowledge), biodiversity assessments, documentation and analysis of local traditional knowledge, and further analysis of dam construction and effects (Environment Canada, 2003).

Much of the research conducted during the NREI developed information on the effects of pulp and paper mill effluents on the aquatic environment. Several other NREI fish or benthic invertebrate studies strictly associated with upstream pulp mills do not fall within the Expanded Geographic Extent, and these studies have not been included. Though not specifically discussed here, these research studies, as well as the Environmental Effects Monitoring program (see section A3.1), provide potential upstream reference information on invertebrate communities, which could prove useful in future analysis of invertebrate trends on these rivers.

B5: WATER SURVEY OF CANADA HISTORIC SUSPENDED SEDIMENT LOAD INFORMATION

As discussed in section A1.2, river velocity measurements are performed to estimate streamflow. At some selected gauges, as streamflow varied, hydrologists also took water samples that were later analysed to determine the quantity of suspended sediments carried by the stream for different flow conditions. Both streamflow and sediment concentration continually change. An important driver is the amount of material that is available for mobilization from stream bed or banks. Due to infrequent observations, a high degree of subjectivity was involved in the daily sediment loading determinations. Uncertainty estimates varied with flow conditions, but values of 100% or more can be demonstrated in this historic data (Greg McCulloch, Water Survey of Canada, pers. comm.). Figures 17 and 18 show the locations of Water Survey and Canada sites that were historically used to estimate sediment loads.

The sediment monitoring program was terminated as part of program review in 1993 (Pietroniro, Environment Canada, pers. comm.). Data from the program are still available, and can be downloaded from the WSC web site.

B6: PANEL ON ENERGY RESEARCH AND DEVELOPMENT (PERD) FOCUSSED STUDIES

Following the conclusion of the Northern Rivers Basin Study, research to further assess and predict potential impacts of hydrocarbon activities occurring in the Alberta oil sands area, and to distinguish these impacts from those produced by naturally occurring hydrocarbon deposits and releases was proposed. This proposal was developed to directly address NRBS research recommendations on oil sands. The proposal was submitted to the Hydrocarbons/Oil Sands and Heavy Oil Research and Development section of the Panel on Energy Research and Development (PERD) in 1997 (Brua *et al.*, 2003).

Individual subcomponents within the resulting PERD study indicated that major tributaries of the lower Athabasca River contained significant levels of naturally derived hydrocarbons. Observed

levels in the mainstem of the river and in the downstream delta were much lower but, as with the tributaries, the available evidence [at that time] suggested that these materials were naturally derived rather than a result of industrial activities within the oil sands area. The studies provided evidence of reduced macroinvertebrate density and community composition in field samples exposed to naturally-derived hydrocarbons as well as reduced macroinvertebrate survival and growth in laboratory toxicity tests, and impacts on some fish reproductive indicators. Collectively, these results suggested the presence of naturally occurring hydrocarbons in the lower reaches of the Athabasca River, a slight to moderate impact of these materials on local biota, and no clear evidence to indicate that local industry was contributing significantly to measured hydrocarbon levels or biotic impacts. These PERD studies played an important role in the design and implementation of local monitoring programs (e.g., RAMP) (Brua *et al.*, 2003).

A sub-component of the PERD program of research was the identification and characterization of natural hydrocarbon release from oil sands deposits in the northern river basins area (Conly *et al.*, 2002, Headley *et al.*, 2001). This project was intended to provide an improved understanding of the spatial distribution, nature and extent of natural hydrocarbon releases to the environment within the oil sands region and to identify biotic communities most at risk from such releases. The primary objectives of this project were to identify the location of natural hydrocarbon release and depositional sites; determine the concentrations of non-aqueous phase liquids (NAPL) in oil sand regions which partition between aqueous and residual phases in the fractures and pore fluids of unsaturated clay soils and; quantify the contribution of hydrocarbon contaminants released to northern rivers from natural oil sand deposits. The spatial distribution, nature and extent of natural hydrocarbon releases to the aquatic environment from the exposed sources of oil sand strata were studied. Initial efforts focussed on assessing the physical fluvial characteristics of the lower Athabasca River basin in the context of natural source contributions of oil sand derived sediment, based on a review of historic sediment data for the lower Athabasca River and an evaluation of channel stability from aerial photography and on-site investigations. In addition to assessing the fluvial geomorphic characteristics of the mainstem of the lower Athabasca River, considerable effort was also focussed on many of the tributaries that incise through the oil sand bearing strata (Conly *et al.*, 2002).

Evans *et al.* (2002) investigated hydrocarbon sources fate and time trends in the Athabasca River and its tributaries, and the Peace-Athabasca Delta, using data from PERD and RAMP samples. Sediments were analyzed for alkylated PAHs and a smaller set for alkanes. Sediment cores were collected in Lake Athabasca, Mamawi, Richardson, Namur and Beaverlodge lakes. Lower molecular weight compounds such as naphthalene and fluorene tended to increase in concentration from upstream sources to downstream depositional areas. Little or no evidence of temporal trends of increasing PAH concentrations in sediment cores collected in Lake Athabasca and the Athabasca delta lakes were found, suggesting no or minimal impact from the oil sands operations. Some PAHs exceeded interim sediment quality guidelines and some bioassay studies showed evidence of toxicity, particularly in the Athabasca delta (Evans *et al.*, 2002).

B7: FOCUSSED STUDIES

B7.1: Water and Sediment Quality Focussed Studies

Alberta Environment carried out five water quality surveys in January to March of 1988 and 1989. The data were compared to previous studies, effluent impacts were assessed, and compliance with the Alberta Surface Water Quality Objectives (ASWQO) and the Canadian Water Quality Guidelines (CWQG) evaluated. Effluents to the Athabasca River at the time were the Hinton pulp mill and municipal effluent (HCE), the Millar Western Pulp Ltd. (MWPU effluent) (1989 only), treated municipal sewage from Whitecourt, Athabasca and Fort McMurray, and the Suncor Oil

Sands process effluent. In both years, river flows during the surveys were about 70% of mean winter flow but were greater than the 1 in 10 year low flow. Effluent impact is generally considered greatest in winter due to low flow and low dilution capacity in the river. During winter, the upper Athabasca flows from the mountains in an alkaline, hard water, clear, base flow condition. As it progresses downstream, tributary inflow tends to alter the major ion composition and increase colour, organic carbon, iron and manganese concentrations. Pulp mill effluents had adverse effects on concentrations of dissolved oxygen, phenolic compounds, trace organic compounds, colour, odour, phosphorus, and manganese. This resulted in non-compliance with the ASWQO and/or the CWQG for oxygen, phenols, colour, odour and phosphorus. Heat in the effluents created an ice-free reach downstream of each mill. In addition, the pulp mill effluents increased river concentrations of sodium, chloride, sulphate, sulphide, suspended solids, tannin and lignin, organic carbon, nitrogen, and bacteria, and zinc. These findings are consistent with assessments carried out previously with regard to the HCE and with regard to the bleached kraft pulp mill on the Wapiti-Smoky River system. Municipal sewage effluents caused small to moderate increases in nitrogen, phosphorus, and bacteria. No effect of the Suncor Oil Sands effluent on river water quality was discernible. Concentrations of calcium, magnesium, bicarbonate, alkalinity, hardness, pH, fluoride, and most metals were not adversely affected by effluent discharges (Noton and Shaw, 1989).

Prior to 1988, most water samples in the Peace River system had been collected from mainstem sites at Dunvegan, the town of Peace River, Fort Vermilion and Peace Point. The most complete record was from Environment Canada's former water quality sampling station at Dunvegan. A number of other sites along the mainstem and tributaries were sampled intermittently by Environment Canada in the 60's and 70's. Most of these data are included in Alberta Environment's water quality database. In 1988, Alberta Environment began an extensive field study to collect data on the existing water quality of the Peace River system in Alberta (Shaw *et al.*, 1990). Mainstem sites were located at key locations such as to provide semi-uniform coverage along the river. Objectives of the study were to:

- Characterize water quality patterns in the Peace River over several seasons and years, from the B.C. border to the confluence with the Slave River, delimiting river reaches using multivariate analyses;
- Identify factors that affect water quality in the mainstem, including tributaries and effluents (point source) and groundwater and diffuse runoff (non-point source);
- Assess mixing of the Smoky and Peace rivers;
- Describe the benthic invertebrate community composition;
- Compare river water quality with Alberta Surface Water Quality Objectives and Canadian Water Quality Guidelines.

Three relatively homogeneous reaches of the river were identified: (a) border to the Smoky River, (b) Smoky River to Fort Vermilion, and (c) Fort Vermilion to the mouth. Reach (b) showed gradual increases of most water quality variables along the reach, attributable to tributary input, the pulp mill, and the abandoned Peace River Oils flowing well. Water quality in Reach (c) was influenced by tributary inflows, but more strongly by the change of bed materials from gravel to sand and silt. Invertebrate community composition also changed between reaches. The upstream reach contained high numbers and diversity, the middle displayed lower total numbers but even higher diversity, and the downstream reach had lower total numbers and diversity, which may be attributable to the sand/silt bottom, which is a relatively inhospitable substrate for invertebrates. Several metals, nutrients and phenolics exceeded water quality guidelines at times. These exceedences were generally associated with increases in suspended solids (Shaw *et al.*, 1990).

The effect of the abandoned Peace River Oils No 1 flowing well on mainstem water quality was evaluated by Alberta Environment in 1989 (Alberta Environment, 1989).

Water quality monitoring and surveys on the Athabasca River were increased substantially after 1987, including winter "synoptic" surveys, new monitoring sites, installation of recording oxygen meters in winter and applied studies to assess impacts or obtain data for modelling. In addition, the Northern River Basins Study was initiated to further investigate the Peace, Athabasca and Slave River systems. Noton and Saffran (1995) presented the findings of water quality monitoring and surveys on the Athabasca River, 1990-93. Data collected prior to 1990 were also included for comparison. The effects of effluents were quantified and evaluated against Alberta Ambient Surface Water Quality Interim Guidelines (AWQG) and Canadian Water Quality guidelines (CWQG). Comparisons were also made with previous winter water quality surveys from 1988 and 1989. At the time of the study, three pulp mills discharged effluent directly into the Athabasca River. Other effluents to the Athabasca included municipal sewage from Jasper, Whitecourt, Slave Lake, Athabasca and Fort McMurray, sewage from Syncrude Canada Ltd., and oil sands wastewater from Suncor Inc. Pulp mill effluent discharges caused increases in colour, odour, phosphorus and phenolic compounds, exceeding AWQG or CWQG during winter. Pulp mill-related increases in sodium, chloride, sulphide, manganese, biochemical oxygen demand, dissolved organic carbon, tannins, lignins, adsorbable organic halides, chlorophenolics and resin acids remained within existing water quality guidelines. Sewage, and to a lesser extent, pulp mill effluents affected concentrations of ammonia, total nitrogen and total and fecal coliform bacteria, but these also remained within guidelines. Pulp mill effluents had a moderate effect on temperature, sulphate and possibly dissolved oxygen and zinc. Similar effluent effects were seen in winter synoptic surveys during 1988 and 1989, although the later surveys indicated lesser effects than in previous years, suggesting improvements in effluent quality (Noton and Saffran, 1995).

The geochemistry and distribution of trace elements in bed and suspended sediments of the Slave River Delta was studied by Stone and English (1998). Sediment was collected in representative areas of the outer, mid and apex portions of the delta. The geochemical composition of sediments showed the deposition of relatively similar material throughout the delta. The composition of trace elements (Cu, Ni, Co, Cr, V, Pb and Zn) was more variable and was related to differences in particle size distribution as well as the sediment source and delivery to the delta. Metal concentrations in several samples exceeded the Severe Effects Level of the Ontario Ministry of the Environment Aquatic Sediment Guidelines. No sediment guidelines were in place for the Northwest Territories. Due to the limited number of samples, data interpretation was qualitative. A larger sample size would be required to make statistical inferences regarding the spatial and temporal variability of sediment geochemistry in the Slave River Delta (Stone and English, 1998).

Due to concerns about potential metal contamination from the decommissioned Pine Point Mine, metal concentrations were determined in water (dissolved and particulate) and surficial sediments of Resolution Bay, Great Slave Lake, near the community of Fort Resolution. This 1996 study extended from west of the decommissioned Pine Point Mine site to the eastern side of Resolution Bay, and in the Slave and Little Buffalo Rivers. Limnological data were also collected to provide insight into water movement and dilution. It was determined that the Slave River was an enriched source of iron, manganese and possibly nickel, suspended sediments, particulates and nutrients. There was no evidence that the water in the study area was being contaminated by the decommissioned mine. Metal concentrations in surficial sediments were sampled at the same sites where the water column was sampled. Metal concentrations in sediments were similar to those observed in suspended sediments in the Slave River, and there was no evidence of contaminated sediments offshore of the decommissioned mine site. As well, a sediment core was collected in a depositional area off the mine site, and analyzed for metals. The core's time period extended from the late 1880s to the early 1990s, and there was no evidence of increased metals concentrations in the core during the mine's operational period (Evans *et al.*, 1998a).

A study was conducted on sediment chemistry in the outer, mid and apex areas of the Slave River Delta by Milburn *et al.* (2000). The mineralogy and major element composition were similar in the outer, mid and apex areas of the delta. Concentrations of copper, cadmium, chromium, lead, arsenic and mercury were significantly higher in the mid-delta. Elevated metal concentrations in this section of the delta were related to geomorphic and hydraulic controls, which caused selective sorting and fining of sediment in smaller mid-delta channels where vegetation is important for sediment trapping and metal cycling. Concentrations of mercury, cadmium and arsenic in all samples exceeded the Potential Effect Level of the Canadian Sediment Guidelines for the Protection of Aquatic Life (Milburn *et al.*, 2000).

Pavelsky and Smith (2009) provided archived data including water surface elevation and water quality parameters measured at points throughout the delta during the summers of 2006 and 2007. These data sets were originally collected to improve understanding of hydrologic recharge processes in low-relief environments and to provide ground-based measurements to validate satellite observations of inundation and sediment transport.

Water quality data on the Athabasca, Peace, and Slave rivers at the boundaries of Wood Buffalo National Park between August 1989 and December 2006 were analyzed by Glozier *et al.* (2009). Detailed statistical summaries for the period of record were provided, and patterns in water chemistry among the three watersheds were analyzed, including comparisons to upstream source waters. Parameters with national guidelines or site specific objectives for the protection of aquatic life were evaluated for excursions, including metals, major ions, and nutrients. Site-specific regression analyses for several parameters with suspended sediment concentration (as measured by non-filterable residue) were provided. Statistical temporal trend analyses (seasonal and yearly) were conducted for 39 water quality parameters, and their relationship to river discharge, specific time periods, and season were analyzed. Water chemistry among the three sampling sites was generally similar, however, patterns between sites were apparent for many parameters. Dissolved oxygen was lowest, while total dissolved solids and most major ions were highest, in the Athabasca River compared with the Peace and Slave Rivers. In these rivers, increased total metal concentrations corresponded to peak discharge and sediment loading. For all metals, ranges overlapped among sites, and for most, medians were similar. For physical and major ion parameters most time trend analyses showed stability in concentration through time. Some changes in nutrient concentrations were noted, depending on site and parameter. Carbon showed few changes through time. Trends in nitrogen concentration were similar in the Athabasca and Peace Rivers with most dissolved forms displaying increasing concentrations, while in the Slave River, at least in the last decade, these parameters showed decreasing trends. No significant trends were detected in phosphorus concentration in the Peace River but in both the Athabasca and Slave Rivers, dissolved and total phosphorus concentrations increased over the period of record. The observed nutrient increases were largely driven by increases during winter months, under conditions of low flow and ice-cover. Results showed that, at least in part, the concentration trends in the Athabasca River were related to the changing discharge regime. Increasing nutrients along with decreasing river discharge appeared to be the largest concern for the study reaches of the Athabasca and Slave Rivers and downstream aquatic ecosystems. Increasing trends in phosphorus have resulted in a change in the trophic status (based on Total Phosphorus concentration) for these reaches by at least one, and in some cases three, trophic levels (Glozier *et al.*, 2009).

Comprehensive monitoring in Alberta rivers [other than cross-border sites] was taken over from Environment Canada by Alberta Environment in 1987, and is now referred to as the Long-Term River Network (LTRN). Initial sampling on the Athabasca River was a single station at the Town of Athabasca. In 1977, a second site was established at Old Fort, 200 kilometres downstream of Fort McMurray. Two more LTRN sites, situated upstream of both Hinton and Fort McMurray, were incorporated into the network in 1999 and 2002, respectively [see Figure 2]. Monthly sampling at these sites over an extended time frame provides high quality data for statistical trend

assessment on some parameters. These data were analyzed to provide both a general overview of water quality conditions in the Athabasca River, in the form of summary statistics and time series graphs for all four LTRN sites, and more in-depth statistical trend analyses on long-term data for the Athabasca and Old Fort monitoring stations. Monotonic trend analyses of water quality data revealed trends in several variables at both the Athabasca and Old Fort sites. Streamflow at both locations was found to be decreasing since 1960. At the same time, significant increasing trends in turbidity, a number of nutrients, and some metals were evident at the Old Fort (downstream) station. Relatively high turbidity, in association with high nutrients and metals, is characteristic of the lower Athabasca River and its tributaries and has resulted in frequent water quality guideline exceedences for several variables. Increasing trends in these parameters, however, suggested an additional influence on water quality in the river. Decreasing flows and, hence, a reduced dilution capacity for point source effluents may be partly responsible. However, anthropogenic disturbance in the watershed may also be a contributor (Hebben, 2009).

B7.2: Water Quantity Focussed Studies

Ice-induced backwater has been shown to be the only method by which flooding has supplied water to perched basins within the Peace-Athabasca Delta. The frequency of such events markedly declined in the mid-1970s. To examine this shift, various hydrometeorological conditions that control the severity of river ice break-up were analysed. Specific emphasis was placed on the roles of flow regulation by the Bennett Dam and climate variability. Flow regulation seemed to have produced only minor changes in factors such as ice thickness and strength, and not to have reduced the flow at the time of break-up. Moreover, regulation has actually led to an increase in spring flow originating from the headwater region. Since the mid-1970s, however, spring runoff has declined in the downstream portions of the basin unaffected by regulation. This has been linked to a decrease in the magnitude of the winter snowpack. Elevated ice levels and winter flows resulting from regulation have further reduced the potential of tributary runoff to produce severe break-up floods. Thus the absence of a high-order event between 1974 and 1992 seems to be related to a combined effect of flow regulation and the vagaries of climate (Prowse and Conly, 1998).

Beltaos (2003, 2007, 2008), Beltaos *et al.* (2006) and Beltaos and Carter (2009) used modelling, field data collection, and analyses of archived records to examine ice-jam flooding in the PAD, and determine parameters required (e.g., threshold flows, spring snowpack), potential frequency under different climate scenarios, and management/mitigation techniques. Modelling indicated that an incoming flow of at least 4,000 m^3 /s is required to produce significant flooding of the delta (Beltaos, 2003). Under climate change models, the ice season could be reduced by as much as 2–4 weeks, while future ice covers would be slightly thinner than at present. More importantly, a large part of the Peace River basin would be expected to experience frequent and sustained mid-winter thaws, leading to significant melt and depleted snow packs in the spring, and even greater reduction in ice-jam flooding (Beltaos *et al.*, 2006). Quantification of the behaviour of ice jams that occasionally form in the middle section of the Peace River indicated that jams make their way to the delta via repeated releases and stalls. This was corroborated by field observations and data (Beltaos, 2007). Further modelling on the effect of antecedent conditions on ice jams in the Lower Peace River indicated that the increase of solid-ice thickness since the 1960s can be related to porous accumulation covers caused by larger freeze-ups flows due to regulation (Beltaos, 2008). Break-up patterns were shown to be strongly influenced by the very low slope of the river, which amplifies the importance of waves generated by ice-jam releases (Beltaos and Carter, 2009).

A winter severity sensitivity analysis using a one-dimensional open channel hydraulic model was performed for four climate scenarios (from mild to severe), and three differing flow conditions

(low, average, and high hydraulic regimes), in an effort to better understand the multiple interactions between ice cover and the hydrodynamic regime of this complex system. The modelling showed that a reduction of winter severity lowered lake levels and river flows. While the effect was of relatively short duration in the rivers, the subsequent reduction in lake levels extends over the summer months. High river flows predisposed flow reversal conditions, and water entered lakes at their outlets if the water levels in the rivers feeding the PAD increased significantly over a short period of time. This flow reversal effect was suppressed during milder winters. Modelling results indicated that extending the ice-cover season (severe winter) by 14 days resulted in an increase of up to 5 cm in water level of large lakes in the PAD, while reducing it by 28 days lowered the levels by almost 10 cm. Short-term variations in river levels reached up to 1.5 m as a result of varying the extent of the ice-cover season. The simulation runs did not consider ice-jam events nor the effect of ice thickness on water levels (Leconte *et al.*, 2006).

B7.3: Biological Focussed Studies

Donald and Kooyman (1977a and b) examined feeding habits, growth, population dynamics and seasonal movements of goldeye in the Peace-Athabasca Delta. Larval goldeye fed mainly on the larger cladocerans and copepods, Corixidae and aerial insects, Yearling and older goldeye had similar feeding habits, with Corixidae being the most frequent food item found in stomachs, but with evidence of on other aquatic and terrestrial invertebrates and small fish. Seasonal as well as annual differences in the feeding habits of adult goldeye were noted, likely reflecting seasonal and annual changes in abundance of various food organisms (Donald and Kooyman 1977a). Goldeye began moving into the Peace-Athabasca Delta area in March, but did not enter the delta lakes until after break-up in the Peace River in May. Mature goldeye spawned in the delta lakes primarily between the middle and the end of May. Goldeye of all ages began migrating from the delta in July. All of these goldeye wintered in the Peace River, probably throughout the lower 150-250 km. In the Mamawi-Claire Lake system, young-of-the-year goldeye were most abundant in Mamawi Lake and along the north and west shores of Lake Claire, but the relative abundance in these locations varied from year to year. Young-of-the-year goldeye were found within a few hundred metres of the shoreline in these lakes, showing a clumped distribution. Unusual year-class abundances and growth rates in the early 1970's were attributed to over-harvest of this population by the 1948-66 commercial fishery (Donald and Kooyman, 1977b).

Walleye were studied in Richardson Lake to document their spawning biology and estimate the contribution of the Richardson Lake spawning population to the Lake Athabasca commercial fishery. Adult walleye movements were examined using tagging, plus young-of-the-year movement was also studied. Water levels and water quality information from Richardson Lake were recorded. Tag returns and fish population data were obtained from the Lake Athabasca commercial fishery. Onset of walleye migration appeared to be linked to the timing of ice lift and access to Richardson Lake. Out-migration took place shortly after spawning in late May. Larval hatching appeared to take place about a week later, and migration of young-of-the-year out of Richardson Lake began in late June and continued through to late July. Data from the Lake Athabasca commercial catch indicated that the Richardson Lake spawning population was not a particularly large contributor to the Lake Athabasca population, and other spawning areas (potentially Lake Claire, Mamawi Lake and the north shore of Lake Athabasca) may have been more important. The Richardson Lake spawning population was apparently not affected by the effect of the Peace River on water levels in the Delta, nor by the weirs on Revillon Coupé and Rivière des Rochers (Summers, 1978).

One of a continuing series of fisheries studies associated with an ice-control structure proposed for the Athabasca River just upstream of Fort McMurray was a study by McCart *et al.* (1982) on lake whitefish from Lake Athabasca, which migrated to spawn in the Athabasca River just

upstream of Fort McMurray. Fish, spawning in the Athabasca River, were tagged, eggs sampled, and population estimates were performed. Some supporting water quality data were collected. Fish were also collected in Lake Athabasca in 15 sampling areas. A comparison of fish collected at the spawning site above Fort McMurray and at two sites in Lake Athabasca was made, to establish how the migratory and sedentary populations might be distinguished. Age and growth, parasite infestations, several meristic characters and one enzyme electrophoresis offered value in distinguishing between populations of river and lake spawners. The river spawners tended to be concentrated at the western end of Lake Athabasca, while the lake spawners predominated to the east, but there was considerable mixing in the central areas (McCart *et al.*, 1982).

Mark-recapture information and catch rates suggested that goldeye migrated from the Peace River to the Claire-Mamawi Lakes system or Lake Athabasca through the Rivière des Rochers, Revillon Coupé and Chenal des Quatre Fourches during the spring of 1977. Catch rates of goldeye were approximately three times higher in each of the Rivière des Rochers and Revillon Coupé than in the Chenal des Quatre Fourches during spring migration. Goldeye accumulated downstream of the Rivière des Rochers and Revillon Coupé weirs during portions of the spring sampling period. Comparisons of meristic characters, age structure, growth and movement of goldeye that were captured in the Rivière des Rochers, Revillon Coupé and Chenal des Quatre Fourches suggested that goldeye that migrated through the three rivers during spring were members of the same group. Goldeye tagged in the Peace-Athabasca Delta moved as far upstream in the Peace River as Peace Point and as far south in the Athabasca River as Fort MacKay. Capture of young-of-the-year goldeye in almost all of the water bodies sampled within the delta suggested that goldeye spawned throughout the region. The distribution of young-of-the-year goldeye and other species that were captured in trawl nets appeared related to some environmental parameters (Kristensen, 1981; Kristensen and Summers, 1981).

A study of water and sediment in Resolution Bay, Great Slave Lake (Evans *et al.*, 1998a), also examined fish from the Little Buffalo and Slave Rivers, and compared their metal and metallothionein concentrations in muscle and organs to fish from other areas. There was no overall evidence that fish in the Resolution Bay area were contaminated by metals from the decommissioned Pine Point Mine (Evans *et al.*, 1998a). A second study was conducted on behalf of Fort Resolution, investigating organochlorine and metal contaminants in predatory fish in the same area (Evans *et al.*, 1998b). Contaminants were analyzed in samples of pike, walleye, burbot and inconnu. Arsenic, cadmium, copper, mercury, lead and zinc concentrations were generally low in most fish; however, in some large pike and walleye, mercury concentrations approached or exceeded the 0.2 µg/g consumption guidelines from Health Canada for frequent consumers of fish. Metal concentrations in fish from several studies were compared, and concentrations were generally similar. Persistent organic pollutants were also examined in the fish from this study (Evans *et al.*, 1998b), but could not be compared with fish from the Slave River study (Sanderson *et al.*, 1997) due to detection limit differences.

During the mid-1990s and through the early 2000s, researchers determined that elevated mercury concentrations were a common occurrence in predatory fish in many lakes in the Mackenzie River Basin (MRB). Higher mercury concentrations were strongly associated with the relatively old age of MRB predatory fish; mean age ranged from 7.6 to 24.9 years for the three species. In contrast, none of the lake trout sampled in eight lakes further south in northern Saskatchewan and Alberta had mean mercury concentrations above 0.5 Hg/g, and fish also were younger (mean age 6 years for the 8 lakes). Mercury concentrations in MRB fish generally increased with fish length, age, and trophic feeding although the nature of these relationships varied with the lake. Mean length was a good predictor of mean mercury concentrations in walleye populations across the study lakes but not for whitefish, lake trout, and pike. Age was a good predictor for lake trout and walleye. Mercury concentrations in water and invertebrates were similar to those observed in more southerly regions where fish do not have elevated mercury concentrations. Mercury concentrations tended to be higher in fish in smaller vs. larger lakes and

as a probable consequence of higher summer epilimnion temperatures, which favour a higher net methylation rate, and higher mercury and methyl mercury concentrations in water which enter these lakes from the watershed (Evans *et al.*, 2005).

The effect of naturally occurring oil sands–related compounds (OSRC) on reproductive function in fish was evaluated by Tetreault *et al.* (2003). The health of slimy sculpin (*Cottus cognatus*) and pearl dace (*Semotilus margarita*) collected from the Steepbank and Ells rivers. Assessment endpoints included gonadosomatic indices, fecundity, and in vitro gonadal steroid production. In vitro gonadal incubations demonstrated lower levels of steroid production at sites along the Steepbank River within the oil sands deposit. Hepatic 7-ethoxyresorufin-O-deethylase (EROD) activity, an indicator of exposure to OSRC, was elevated twofold at the site with natural compounds and up to tenfold at the site adjacent to development, compared to EROD activity in fish from the reference site. Fish collected in the Ells River had a threefold induction in EROD activity but no significant reduction in steroid production when compared to reference fish. No consistent alterations in gonadal development were seen in fish collected from sites within the oil sands deposit (Tetreault *et al.*, 2003).

In April of 2005, the Athabasca Chipewyan First Nation (ACFN), with support from Canadian Natural Resources Ltd. (CNRL), contracted Hatfield Consultants Ltd. to assess the health of large-bodied fish in Richardson (Jackfish) Lake and the Old Fort River, particularly with regard to their safety for human consumption. The study was commissioned to evaluate key fish species identified by ACFN members as resources used to sustain traditional ways of life. These resources include resident fish populations of the region, particularly in Richardson (Jackfish) Lake in the Athabasca River Delta, and the Old Fort Bay/Old Fort River area along Lake Athabasca. Lake whitefish, northern pike and walleye, but also lake trout, Arctic grayling, and suckers, continue to support active ACFN fisheries and represent important food, economic and cultural resources. Existing fisheries and associated aquatic environmental information for these water bodies was consolidated from existing literature and data sources, and from ACFN Traditional Ecological Knowledge (TEK), which was identified during a pre-field meeting with ACFN Elders, and over the course of this study through ongoing discussions with ACFN representatives. Assessment of existing fish health in these water bodies was undertaken (Hatfield Consultants Ltd, 2006).

The Slave River Environmental Quality Monitoring Program was established cooperatively between the government of the Northwest Territories and federal government agencies in 1991. A 5-year program was conducted to examine the quality of the water, suspended sediment, and fish in the territorial portion of the Slave River and to establish a baseline data set for comparison purposes in future monitoring programs. Additionally, an assessment of the benthic invertebrate population was undertaken. A third goal was the examination of stable isotope ratios of carbon, sulphur, and nitrogen in Slave River fish. The benthic invertebrate survey was conducted in 1990 and 1991. The study concluded that the abundance of benthic invertebrates at the numerous sites examined in the Slave River was very low and organisms such as bivalve molluscs or large oligochaetes that had been used in other biomonitoring studies were rare or absent. Over 90% of the invertebrates collected from the Slave River were chironomids or small oligochaetes and comparisons of benthic invertebrate communities in the Slave River Delta indicated that few changes in percent composition or diversity had occurred over a 10-year period. The benthic invertebrate survey provided a baseline for future population analysis. Analysis of the stable isotope ratio of sulphur in fish from the Slave River indicated at least two significant food sources. One source was probably from Great Slave Lake, while the other was probably upstream of Fort Smith. Also, the stable isotope of carbon indicated that the food source was via different pathways and may have included benthic as well as pelagic origins. Overall contaminant body burdens were generally very low or below analytical detection (McCarthy *et al.*, 1997).

C: FURTHER WORK

- Further literature search for historic documents including Alberta Environment past and present fish monitoring programs may be useful.
- The Department of Fisheries and Oceans may also be able to provide further information on past and present fish monitoring programs.
- Information on licensed effluents in the Expanded Geographic Extent north of 60 would be useful.
- Further searches for benthic invertebrate reports and papers, particularly related to the Peace-Athabasca Delta and Slave River, should be undertaken.

D: IMPORTANT NON-GOVERNMENT ORGANIZATIONS

D1: CUMULATIVE ENVIRONMENTAL MANAGEMENT ASSOCIATION (CEMA)

In 1998, in conjunction with regional stakeholders and other regulators, Alberta Environment led the creation of the Regional Sustainable Development Strategy (RSDS) for the Athabasca Oil Sands area, based on the anticipation of increasing development in the oil sands region. The RSDS identified and prioritized 72 environmental issues within the oil sands region that should be studied in light of the projected growth. The diversity of environmental values and interest in the region prompted the need for a multi-stakeholder forum to establish environmental management objectives for the region. The Cumulative Environmental Management Association (CEMA), was formed, in partnership with Alberta Environment and Alberta Sustainable Resources Development, and mandated to address 37 of the RSDS issues. CEMA was to provide recommendations to regulators on managing potential cumulative environmental effects using an array of environmental management tools such as environmental limits or thresholds (CEMA website).[2]

CEMA's Goals are to:

- Recommend management frameworks, best practices and implementation strategies that address cumulative effects on air, land, water and biodiversity to protect, sustain and restore the environment and to be protective of human health.
- Follow-up with members on the status of implementation of management frameworks, best practices and implementation strategies.
- Actively promote inclusive dialogue and information exchange by:
    - Encouraging organizations affected by regional activity to be engaged in CEMA,
    - Providing a forum conducive to Aboriginal involvement and participation,
    - Communicating the direction, activities, and results of CEMA to internal and external stakeholders,
    - Communicating with executive levels of stakeholder organizations,
    - Responding to issues brought forward by members, and
    - Assisting members to develop the capacity to meaningfully contribute to CEMA work.
- Align CEMA management frameworks, best practices and implementation strategies with Government priorities.

[2] Editor's note: the CEMA report library became public just after this writing, and constitutes a valuable resource for information developed through CEMA projects and funding.

- Work with other regional environmental multi-stakeholder groups and organizations to coordinate CEMA's work developing management frameworks, best practices and implementation strategies (CEMA website).

CEMA includes 5 major working groups: Air, Reclamation, Groundwater, Surface Water and Sustainable Ecosystems. Each working group may have one or more task groups within the parent group. For example, the Surface Water Working Group consists of the parent group and one task group, the Monitoring Technical Task Group (MTTG) (CEMA website).

MTTG projects include a) status and trend monitoring and b) knowledge gaps. Of the fourteen projects, five were to be initiated in 2011. The fish program proposed to conduct fish capture at replicate sites along the Lower Athabasca River which was to be repeated annually. If tissue sampling were included this would provide extensive coverage of the river. The program is adapted from that already being implemented along other large rivers in Canada and the USA (Peace, Columbia and Colorado Rivers).

Winter ecology projects relate to the concerns over low flow periods and the potential limiting conditions that occur when channels are cut-off due to ice conditions, with special attention to dissolved oxygen levels that may become lethal at this time under ice and low or no flow (CEMA website).

CEMA Status and Trend Monitoring:

- Fish population status and trends;
- Gauging and reporting of water withdrawals;
- Installation of a gauge near Firebag confluence with winter capability;
- Improve accuracy and timeliness of winter flow monitoring at Fort McMurray;
- Hydroclimatic trend analyses and modeling.

Knowledge Gaps:

- Validation of the walleye evaluation criteria;
- Beaver and muskrat in the delta;
- Riparian areas in the delta;
- Winter ecology in the delta – hydraulic modelling, mesohabitat, dissolved oxygen;
- Navigation in mainstem and delta;
- Dissolved oxygen in river segments 2-5;
- Access to tributaries;
- Perched basins in the delta;
- Connectivity of Richardson Lake during the open water season (CEMA website, and Jeff Shatford, Wood Buffalo National Park, pers. comm.).

D2: PEACE-ATHABASCA DELTA ECOLOGICAL MONITORING PROGRAM (PADEMP)

The Peace-Athabasca Delta, one of the world's largest freshwater deltas, is situated at the western end of Lake Athabasca where the Peace, Athabasca and Birch rivers converge. The delta provides some of the most significant waterfowl breeding and staging habitat in North America, is a major spawning site for fish migrating between delta lakes and major rivers, provides habitat for the world's largest free-roaming herd of threatened wood bison, and supports moose, muskrat and other species important to local people who have hunted, trapped and fished in the delta for centuries. The delta is recognized as a RAMSAR Wetland of International Importance. However, the PAD is also vulnerable to the impacts of expanding regional industrial development within the Peace-Athabasca-Slave drainage basin, including hydroelectric development, water withdrawals, oil and gas exploration and production, agriculture, forestry, and pulp and paper production. Changes in climate are also impacting the hydrology of the delta, and

these impacts are expected to increase in the future. To better understand how the PAD may be influenced by regional industrial development and climate change, a comprehensive ecological monitoring program is required. The goal of this long-term program will be to measure, evaluate, determine and report on the ecological integrity of the delta in support of effective environmental stewardship. The program will be developed and implemented by Aboriginal, provincial, territorial and federal government partners, will build upon the work of previous cooperative programs such as the Northern River Basins Study, the Peace-Athabasca Delta Technical Studies and the Northern Rivers Ecosystem Initiative, and will complement (rather than duplicate) existing regional monitoring efforts, including Aboriginal community-based monitoring programs. Integration of traditional ecological knowledge and "western" science will characterize program design, development and implementation. The program will inform local communities and governments alike through the generation of publicly available data and regular "State of the Peace- Athabasca Delta" reports (PADEMP, 2009).

PADEMP Members:

- Mikisew Cree First Nation
- Salt River First Nation
- Smith's Landing First Nation
- Little Red River Cree First Nation
- Katl'odeeche First Nation
- Deninu'Kue First Nation
- Fort Chipewyan Métis Association
- Fort Smith Métis Association
- Fort Résolution Métis Association
- Hay River Métis Association
- Parks Canada – Wood Buffalo National Park
- Environment Canada
- Department of Fisheries and Oceans
- Aboriginal Affairs and Northern Development Canada (NWT)
- Government of the NWT – Environment and Natural Resources
- Alberta Environment and Sustainable Resource Development
- Ducks Unlimited
- World Wildlife Fund

The Mandate of the Peace-Athabasca Delta Ecological Monitoring Program is to determine, measure, evaluate and communicate the state of the Peace- Athabasca Delta ecosystem including any changes to this ecosystem that result from cumulative regional development, and make recommendations to government for changes to regulations and policies and water management practices as needed to restore, protect and safeguard the ecological integrity of the Peace-Athabasca Delta (PADEMP, 2009).

The objectives of the Program are to:

- Identify the key elements and processes that can and should be monitored to characterize Peace-Athabasca Delta ecological integrity, and set clear and measurable objectives for each element to be monitored;
- Assemble existing data and collect additional data to characterize variability in the Peace-Athabasca Delta;
- Develop and implement monitoring and assessment activities that are grounded in both traditional ecological knowledge (TEK) and western science;
- Identify potential threats to the Peace-Athabasca Delta ecological integrity, and monitor the environment of the Peace-Athabasca Delta to detect and assess cumulative effects and regional trends;

- Collect and compare data against which predictions can be assessed and, where required, identify mitigation measures;
- Identify studies and research (traditional ecological knowledge and western science) as needed to augment the program;
- Communicate monitoring and assessment activities and results to program members, local communities, and the general public, including but not limited to regular "State of the Peace-Athabasca Delta" reports;
- Coordinate communication among other monitoring groups/agencies to exchange data, reports and approaches as needed;
- Annually review and adjust the program to incorporate monitoring results, technological advances, and community concerns;
- Conduct a periodic peer review (in conjunction with production of the State of the Delta reports) of the program's objectives against its results, and recommend adjustments necessary for the program's success (PADEMP, 2009).

D3: SLAVE RIVER AND DELTA PARTNERSHIP

Communities along the Slave River and Delta are concerned about changes to the environment. There are several potential sources of environmental change to the Slave River and Delta. Hydroelectric development has affected water and sediment quantity. The Slave River Watershed has been affected by historic transport of uranium and hydrocarbons. There is concern about effects of upstream oil sands development.

In 2010, the Slave River and Delta Partnership was formed to support and coordinate community involvement in aquatic monitoring along the Slave River and the Slave River Delta. This partnership promotes implementation of Keys to Success, from Northern Voices, Northern Waters: The NWT Water Stewardship Strategy, which was created based on input from all water partners in the NWT. The strategy is built on a foundation of western science and traditional and local knowledge. The Slave River Partnership includes the communities of Fort Smith and Fort Resolution, Salt River, Smith's Landing and Deninu K'ue First Nations, the NWT Métis Nation and Fort Smith and Fort Resolution Métis Councils, Department of Environment and Natural Resources (ENR) and Municipal and Community Affairs (MACA) (both Government of the Northwest Territories), Aboriginal Affairs and Northern Development Canada, Fisheries and Oceans Canada, Parks Canada, Environment Canada, Aurora Research Institute, Aurora College, Environmental Non-governmental Organizations, and academics from Wilfrid Laurier University and the University of Waterloo.

The partnership applied to several funding sources to produce a "State of the Slave River and Delta Report" and a "Gap and Vulnerability Assessment" to prioritize community-based monitoring initiatives. Among other parameters, the partnership will focus on water quality and fish health. Information resulting from this project will help to inform research and monitoring activities related to mandates under these Acts.

Another recent initiative under the partnership is participation in a regional scale (Slave and Athabasca River) fish health study. Fish from the Slave River near Fort Resolution and Fort Smith (NWT), and the Athabasca River near the communities of Fort Chipewyan, Fort McKay and Fort McMurray (Alberta) are being collected by community members during "Community Fishing Events". University of Saskatchewan and DFO researchers will collect samples to assess fish health (including gene expression and histology), and assess metal and organic contaminant concentrations. The results of sample analyses will be reported back to the communities. Funding is being provided to University of Saskatchewan researchers by the Pew Charitable Trusts and the Boreal Songbird Initiative. Researchers from the University of Manitoba will be working with Aboriginal organizations to collect traditional and local knowledge regarding aquatic ecosystem

health, specifically related to fish and water quality (Erin Kelly, Government of the Northwest Territories, pers. comm., on behalf of the Slave River and Delta Partnership).

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FIGURES

Figure 1: Oil Sands areas and deposits in the Athabasca and Peace River basins.

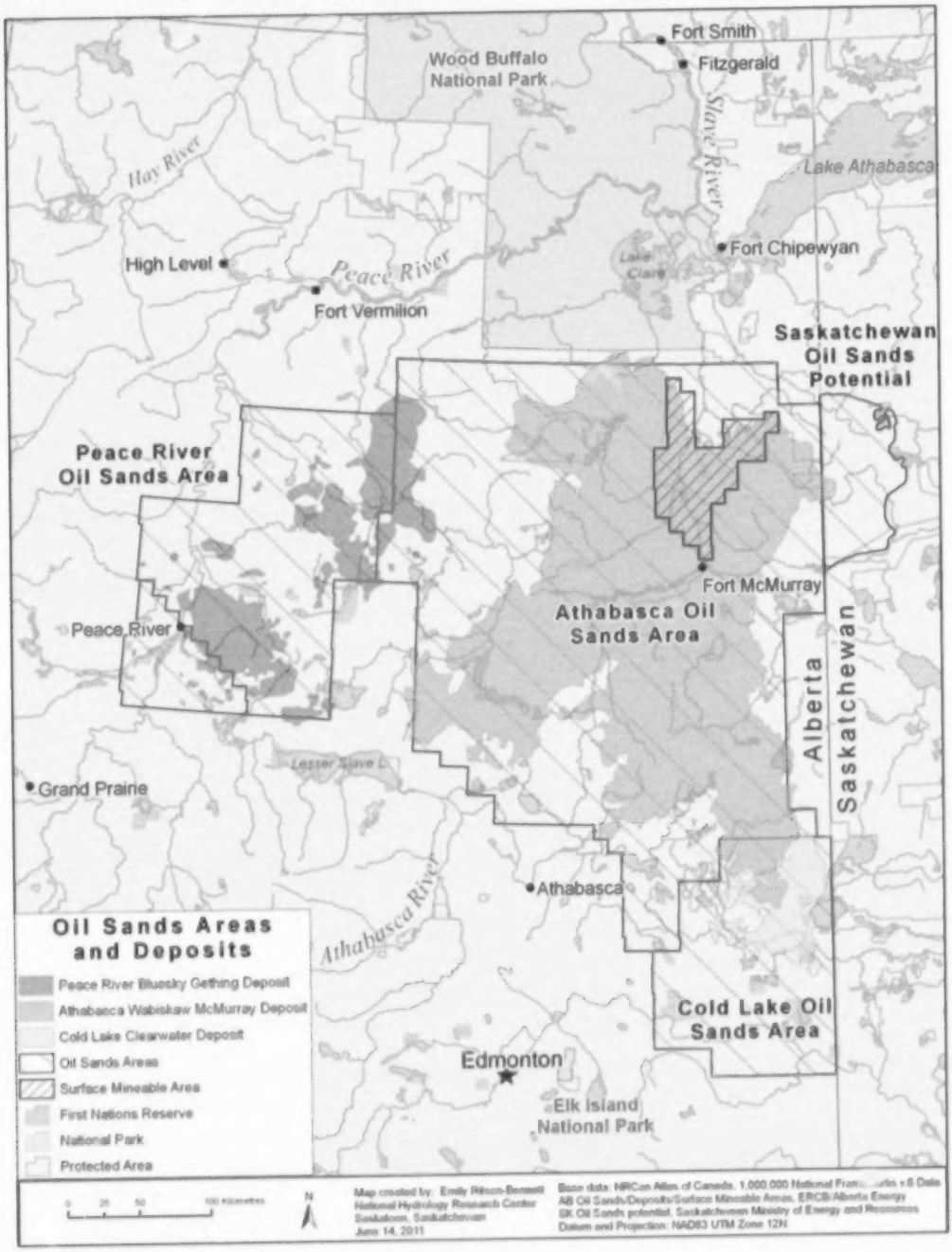


Figure 2: Long-term Environment Canada (EC), Alberta Environment (AENV), BC Environment (BC Env) and Aboriginal Affairs and Northern Development Canada (AANDC) water quality monitoring sites in the Athabasca, Peace and Slave River basins.

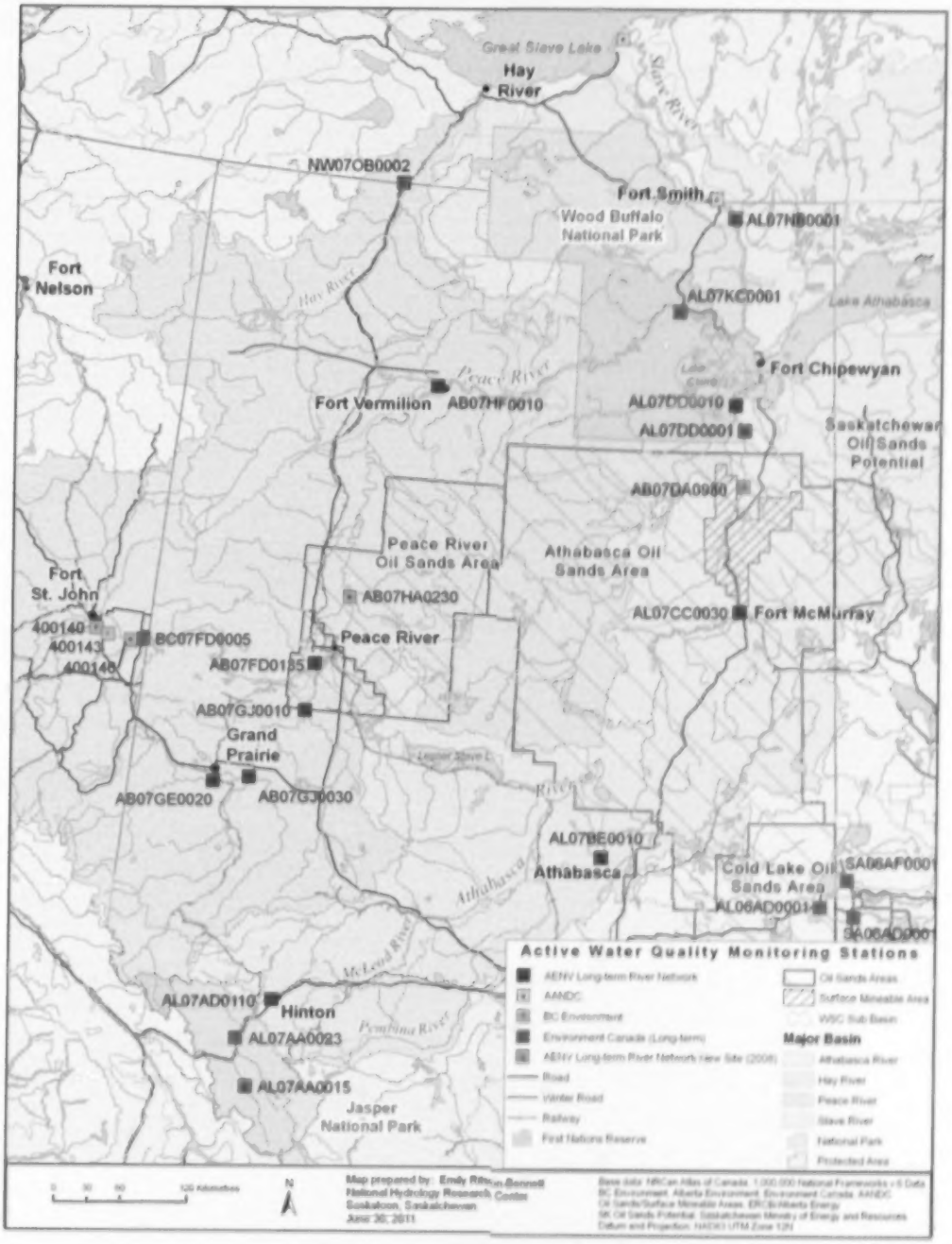


Figure 3: Locations of long-term EC, AENV and AANDC water quality monitoring sites in the Expanded Geographic Extent.

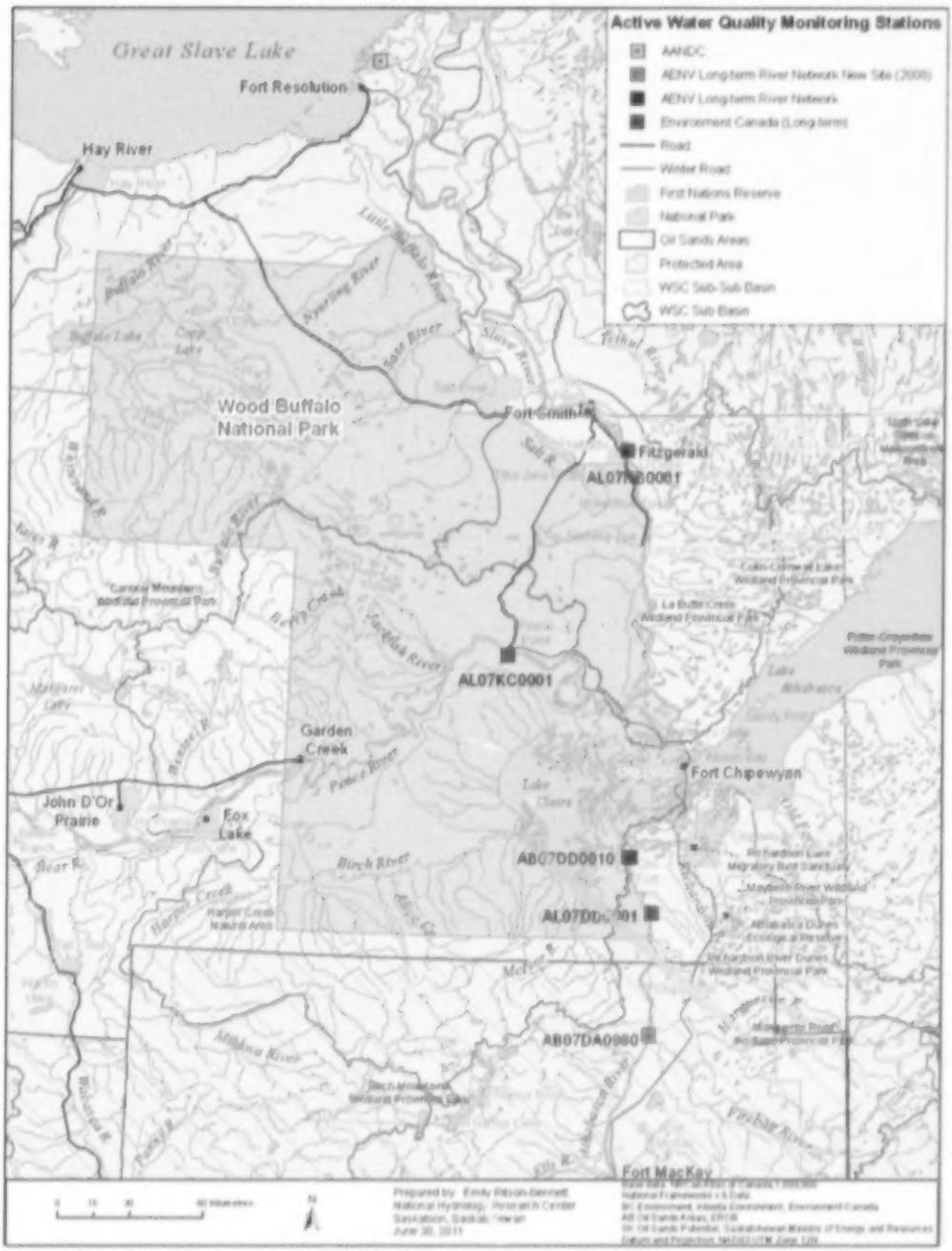


Figure 4: Locations of long-term EC and AENV water quality monitoring sites in the Peace-Athabasca Delta.

Figure 5: Water Survey of Canada hydrometric stations, EC and AENV climate stations and AENV snowpack measurement sites. Snow survey sites north of 60 are operated by AANDC. Snow sites in BC are operated by BC Env.

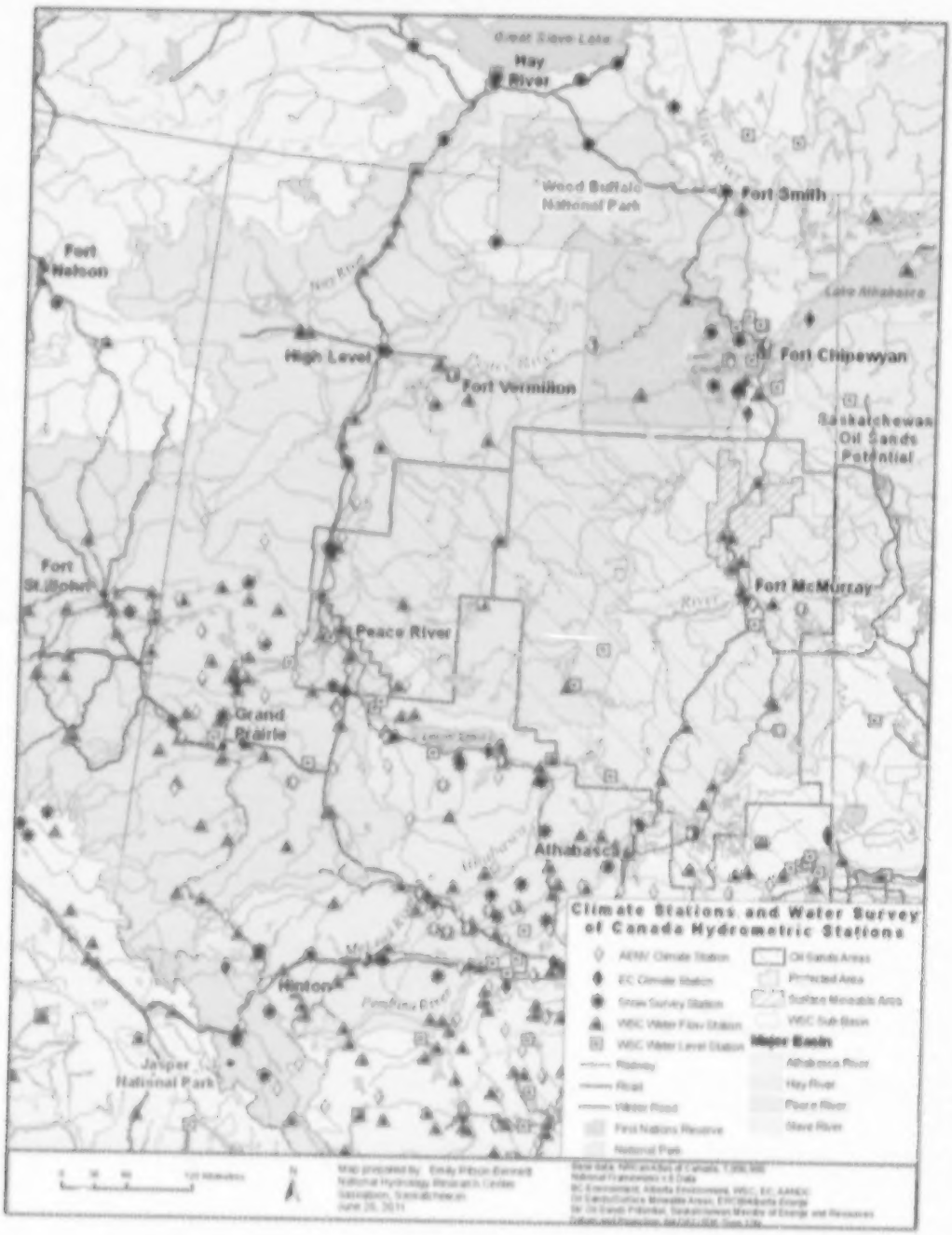


Figure 6: Locations of Water Survey of Canada hydrometric stations, EC and AENV climate stations, and AENV and AANDC snowpack measurement stations in the Expanded Geographic Extent.

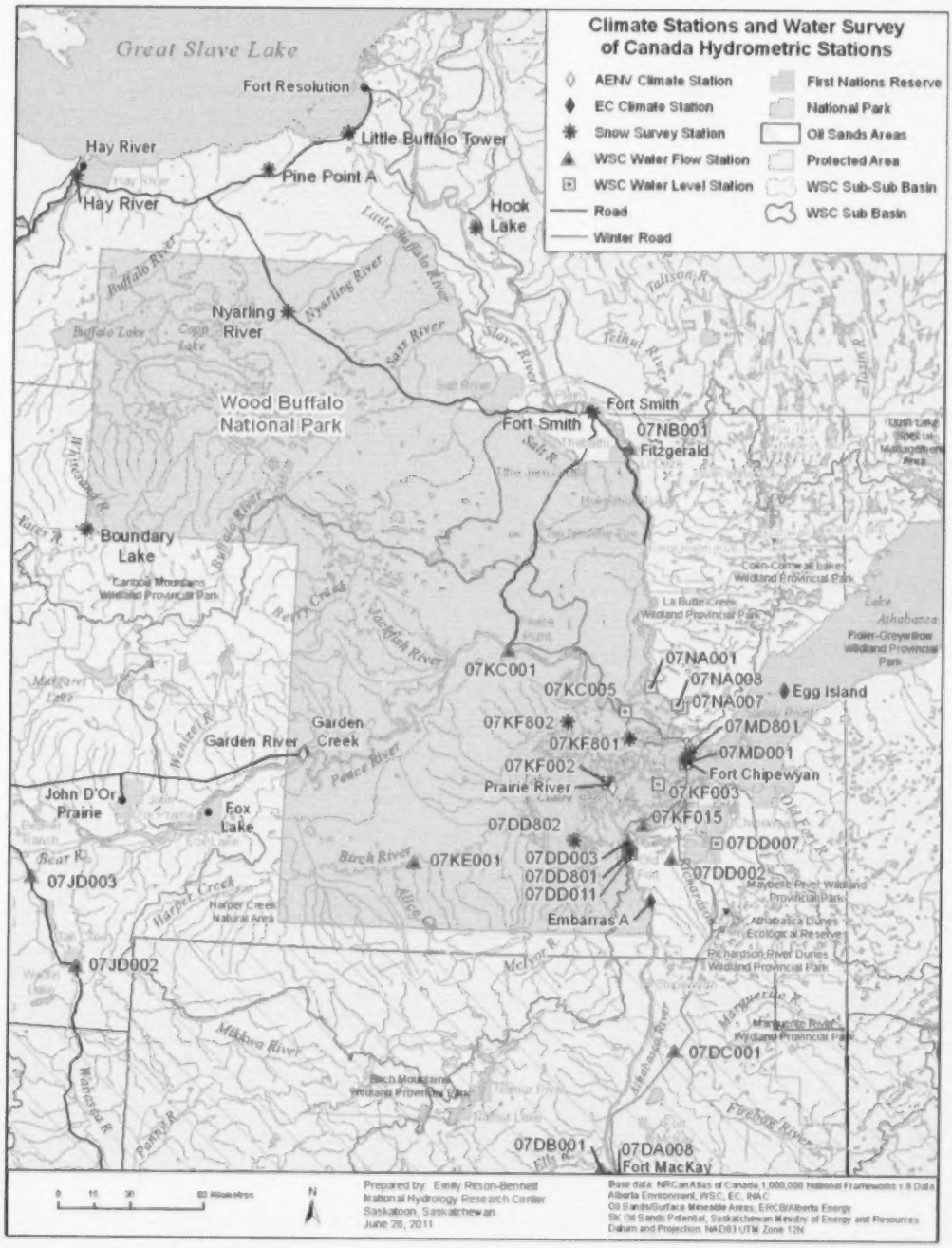


Figure 7: Water Survey of Canada hydrometric stations, EC and AENV climate stations, and AENV snowpack measurement sites in the Peace-Athabasca Delta. AWOS = Automated Weather Observing System; CS = Climate Station; A = Airport; AWOS A = AWOS at an airport.

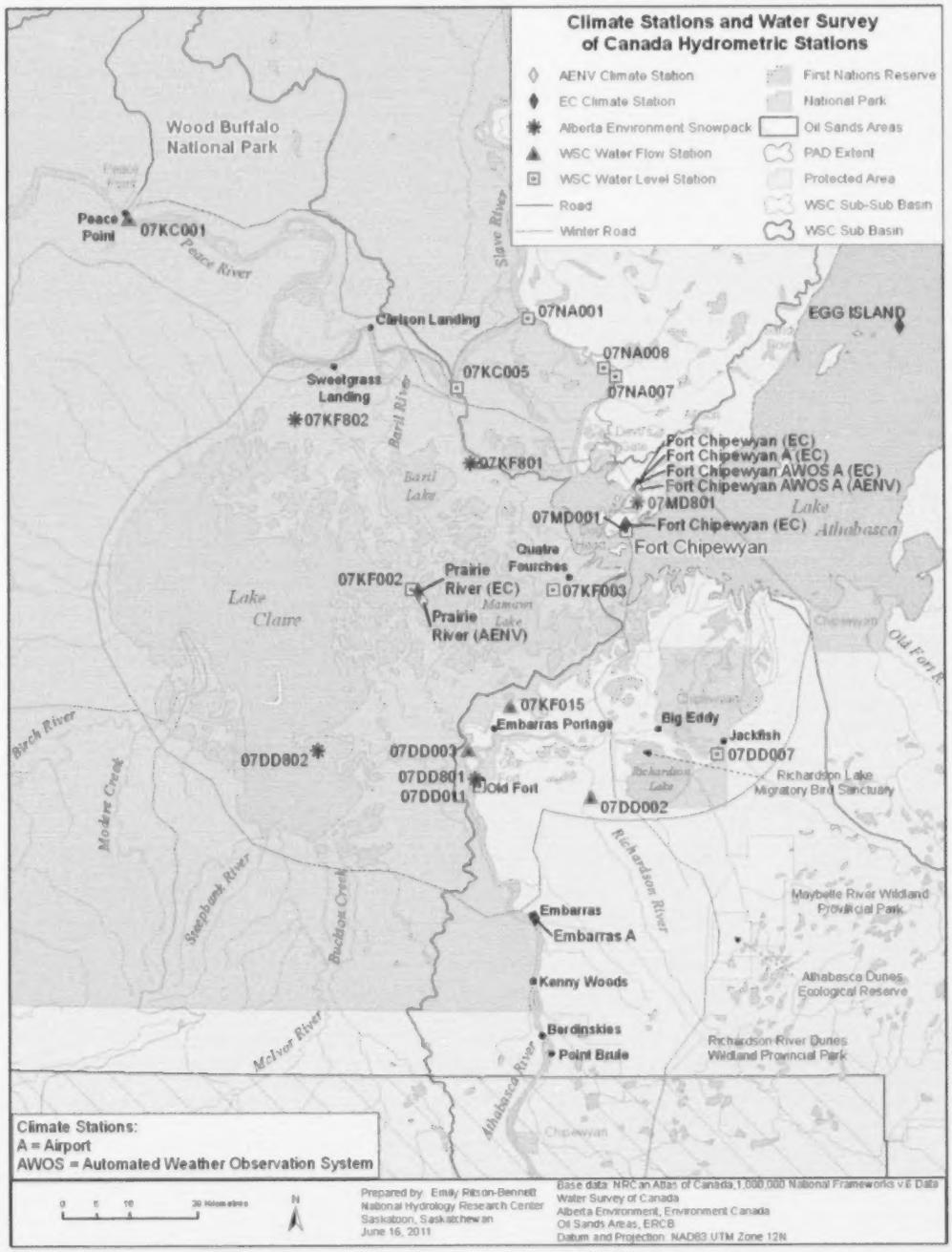


Figure 8: Parks Canada Agency Peace-Athabasca Delta study areas for water extent and plant community change over time.

Peace Athabasca Delta Water Extents and Plant Community Change Over Time (Study Area)
Road
Winter Road
First Nations Reserve
National Park
Protected Area
WSC Sub-Sub Basin
WSC Sub Basin
La Butte Creek Wildland Provincial Park
Wood Buffalo National Park
Peace Point
Peace River
Slave River
Carlson Landing
Sweetgrass Landing
Baril River
Baril Lake
Peace
Lake Athabasca
Fort Chipewyan
Lake Claire
Mamawi Lake
Quatre Fourches
Mid-Delta
Athabasca
Birch River
Embarras Portage
Big Eddy
Jackfish
Richardson Lake
Richardson Lake Migratory Bird Sanctuary
Old Fort
Modeste Creek
Steepbank River
Richardson River
Embarras
Maybelle River Wildland Provincial Park
Old Fort R
Description: A combination of optical and radarsat satellite imagery is used along with ground truthing to map the extent of surface water, and the associated vegetation in the Peace-Athabasca Delta (PAD) each spring.
Duration: 1996 - 2010 (ongoing)
Objective: Identify and quantify any long term trends in the water characteristics of the PAD. What is the areal extent of wetted area in the Peace-Athabasca Delta during the growing season? Is there a greater than 10% decrease in water extent over a 10 year period?
Project Rationale: The PAD is a huge (3,900 km^2) wetland complex which provides important habitat for wildlife and migrating waterfowl. The construction of the W.A.C. Bennett Dam in 1968, and global climate change have raised concerns that the frequency of flooding in the PAD may be decreasing. Fewer floods could result in the numerous perched wetland basins in the PAD drying out and becoming overgrown with non-productive willow shrubs. Remote sensing provides an economical way to monitor this large and remote area.
0 5 10 20 Kilometers
N
Prepared by: Emily Ritson-Bennett
National Hydrology Research Center
Saskatoon, Saskatchewan
June 16, 2011
Datum and Projection: NAD83 UTM Zone 12N
Base data: NRCan Atlas of Canada,1,000,000
National Frameworks v6 Data
Parks Canada - Peace Athabasca Delta water extents & plant community change over time (remote sensing)

Figure 9: RAMP active and discontinued sediment quality and invertebrate monitoring sites in the Expanded Geographic Extent (with insert from the surface-mineable area).

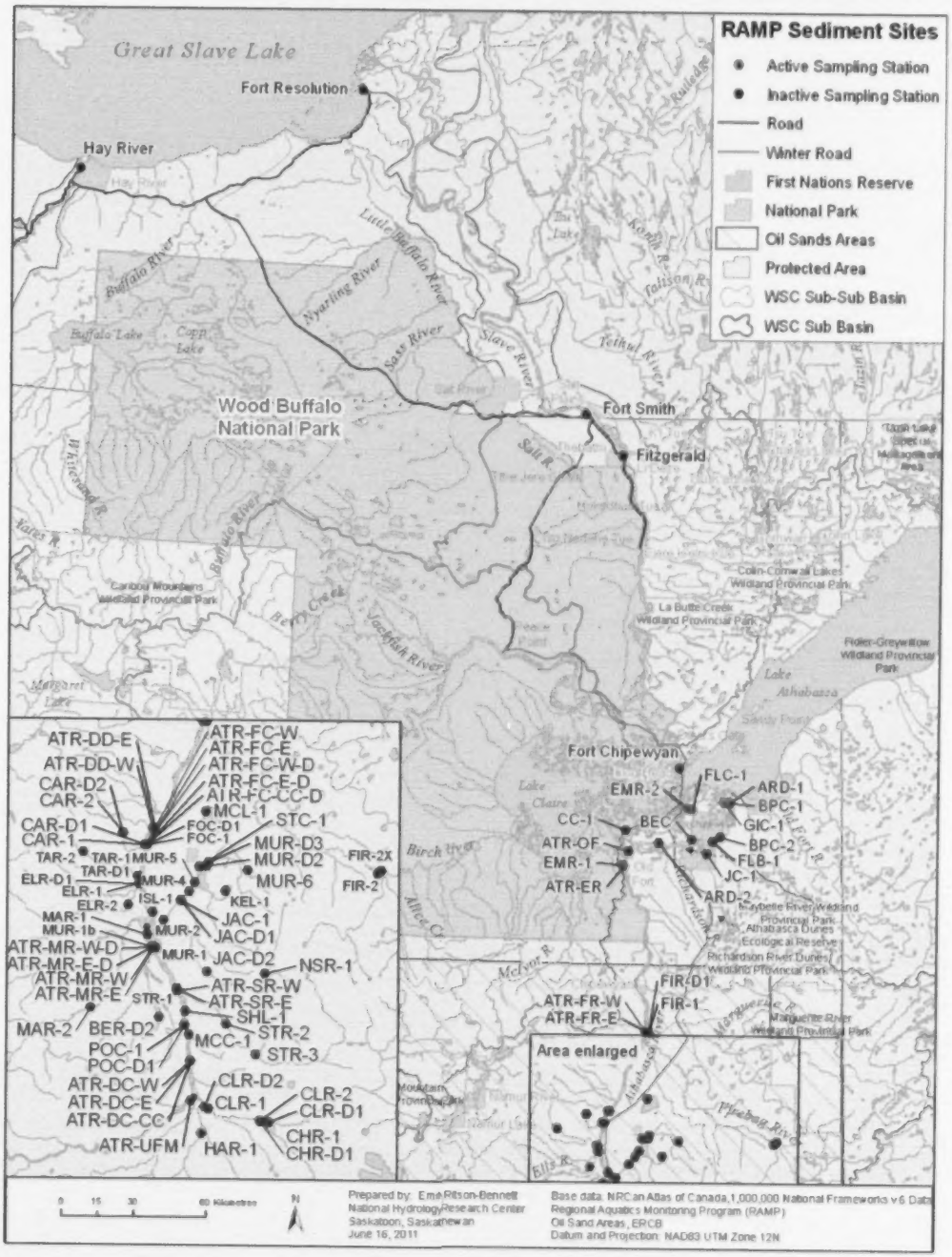


Figure 10: Locations of RAMP active and discontinued sediment quality and invertebrate monitoring sites in the Peace-Athabasca Delta.

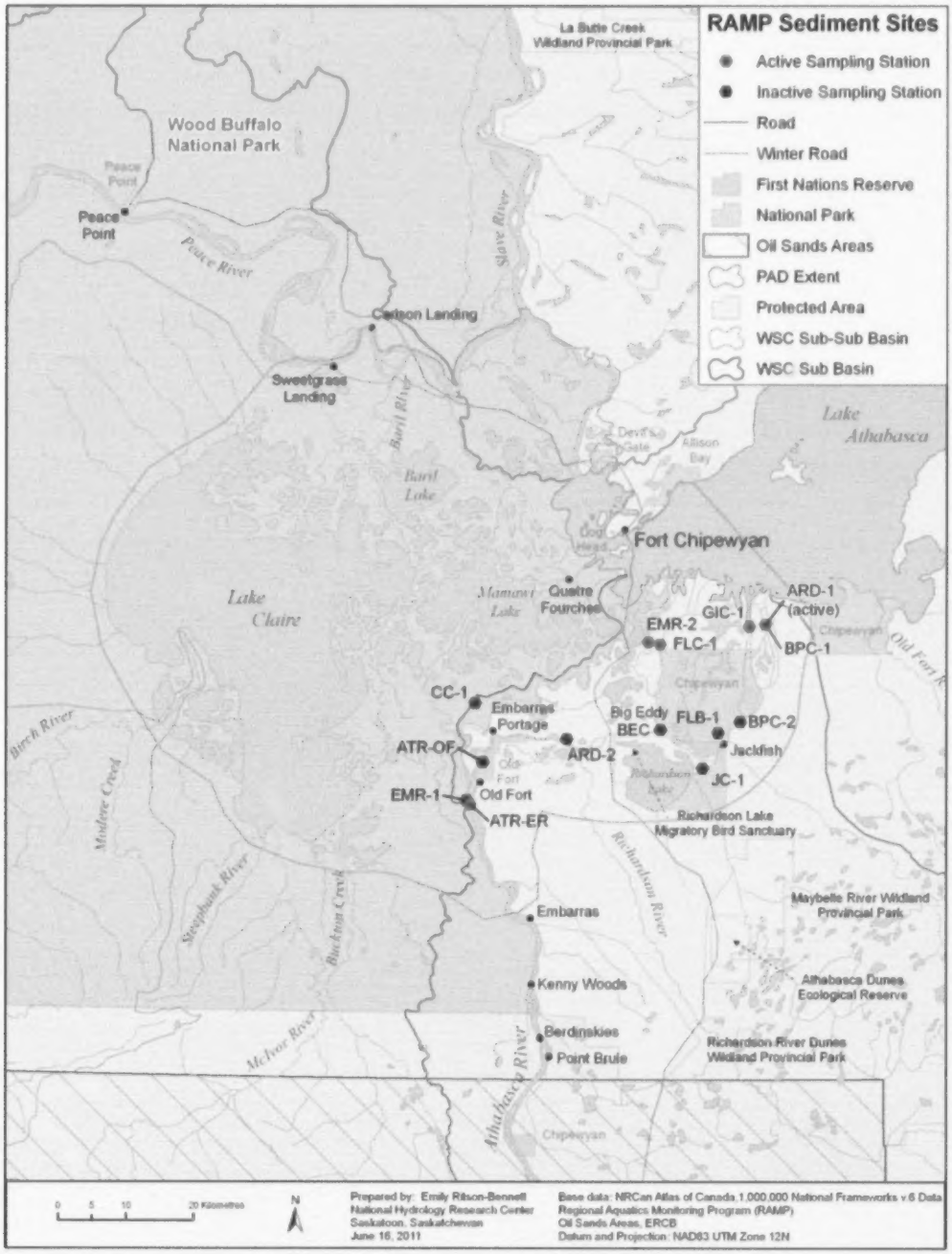


Figure 11: Pulp and paper mill and metal mining facilities subject to the Environmental Effects Monitoring program, in the Athabasca and Peace River basins.

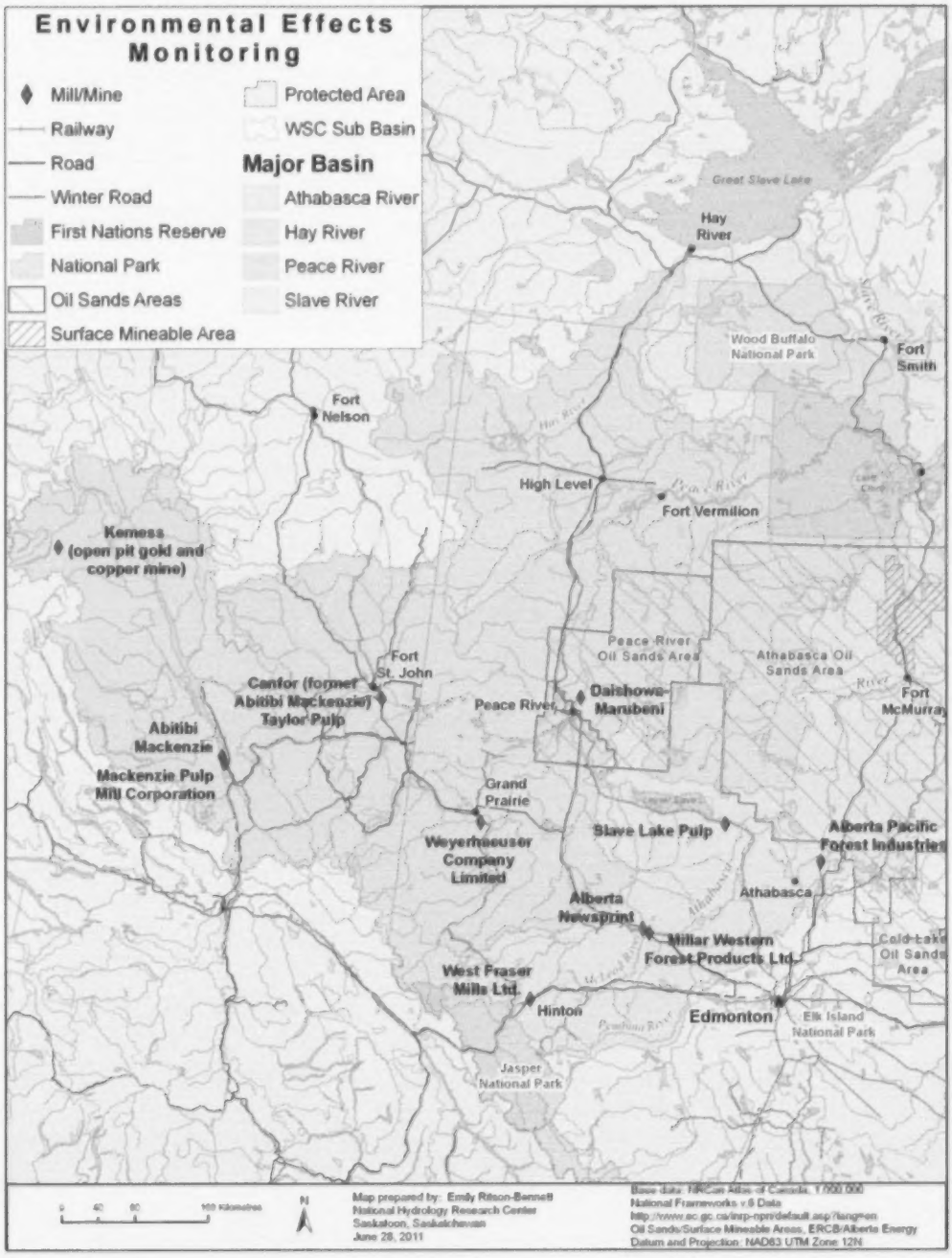


Figure 12: Historical focussed studies: locations of Alberta Oil Sands Environmental Research Program (AOSERP) water quality sampling sites, summarized by Corkum (1985).

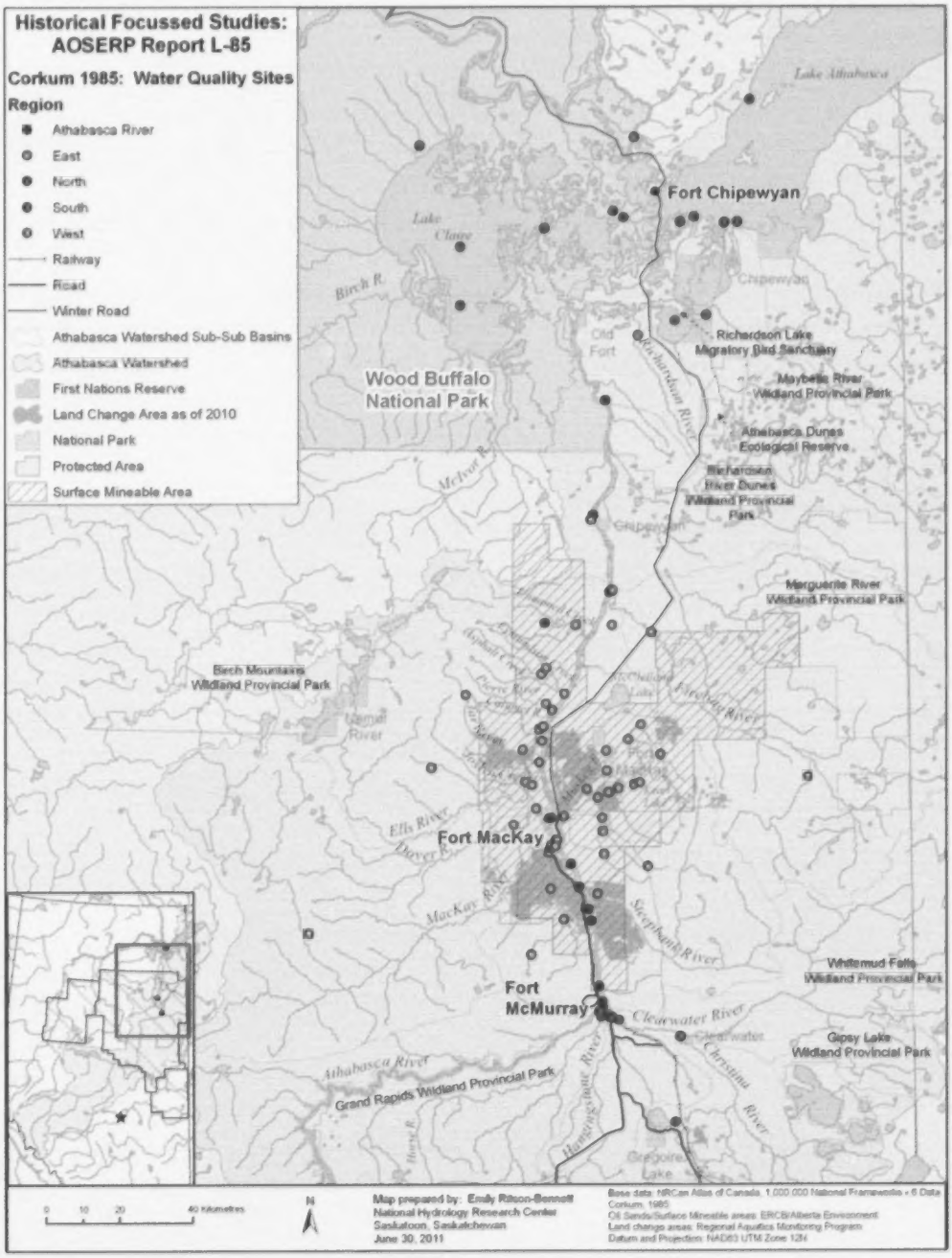


Figure 13: Historical focussed studies: locations of AOSERP sampling sites for contaminants in aquatic biota (Lutz and Hendzel 1976).

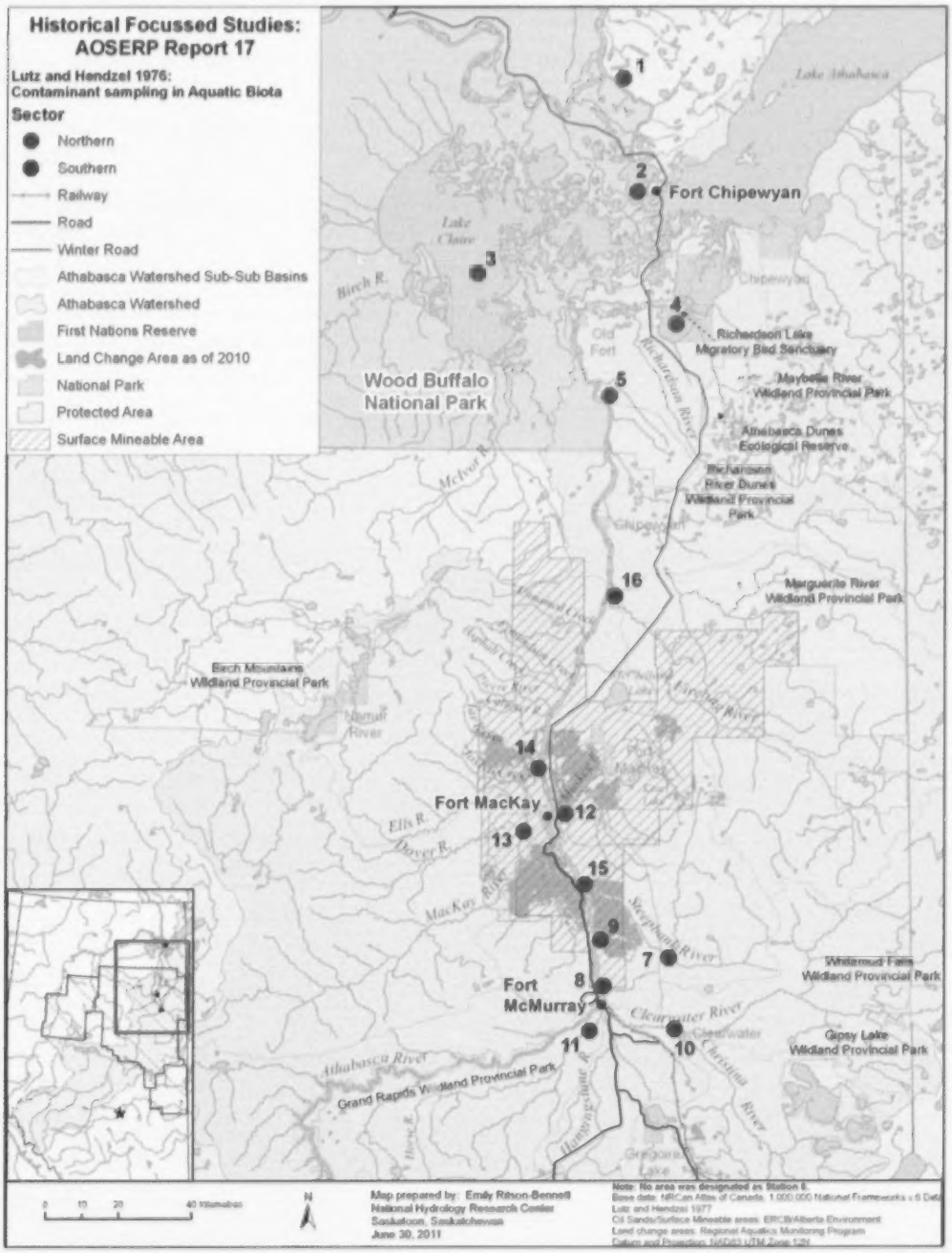


Figure 14: Historical focussed studies: locations of Northern River Basins Study (NRBS) sediment samples analyzed for metals and PAH concentrations, in the Athabasca, Peace and Slave River basins.

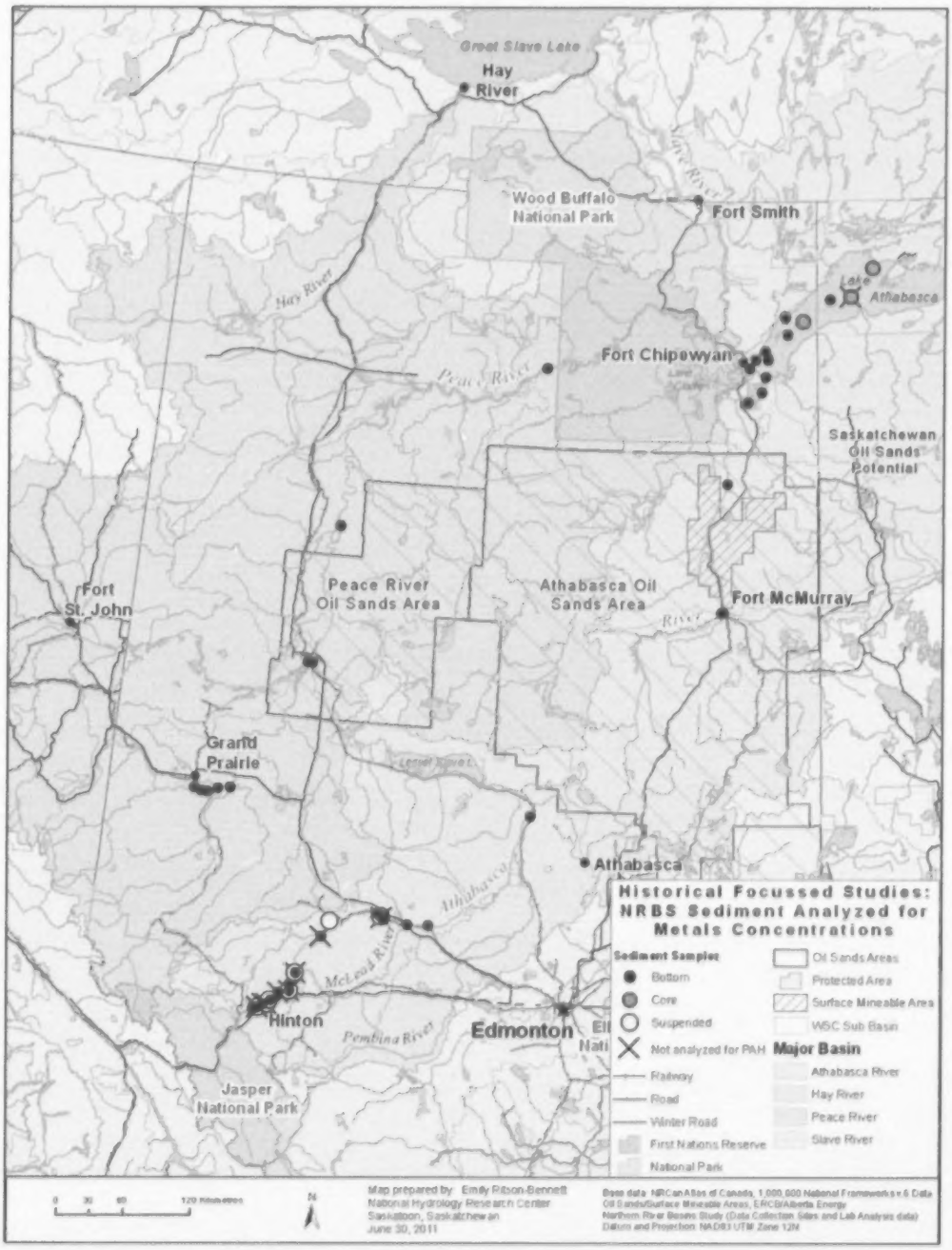


Figure 15: Historical focussed studies: NRBS fish samples analyzed for metals and PAH concentrations.

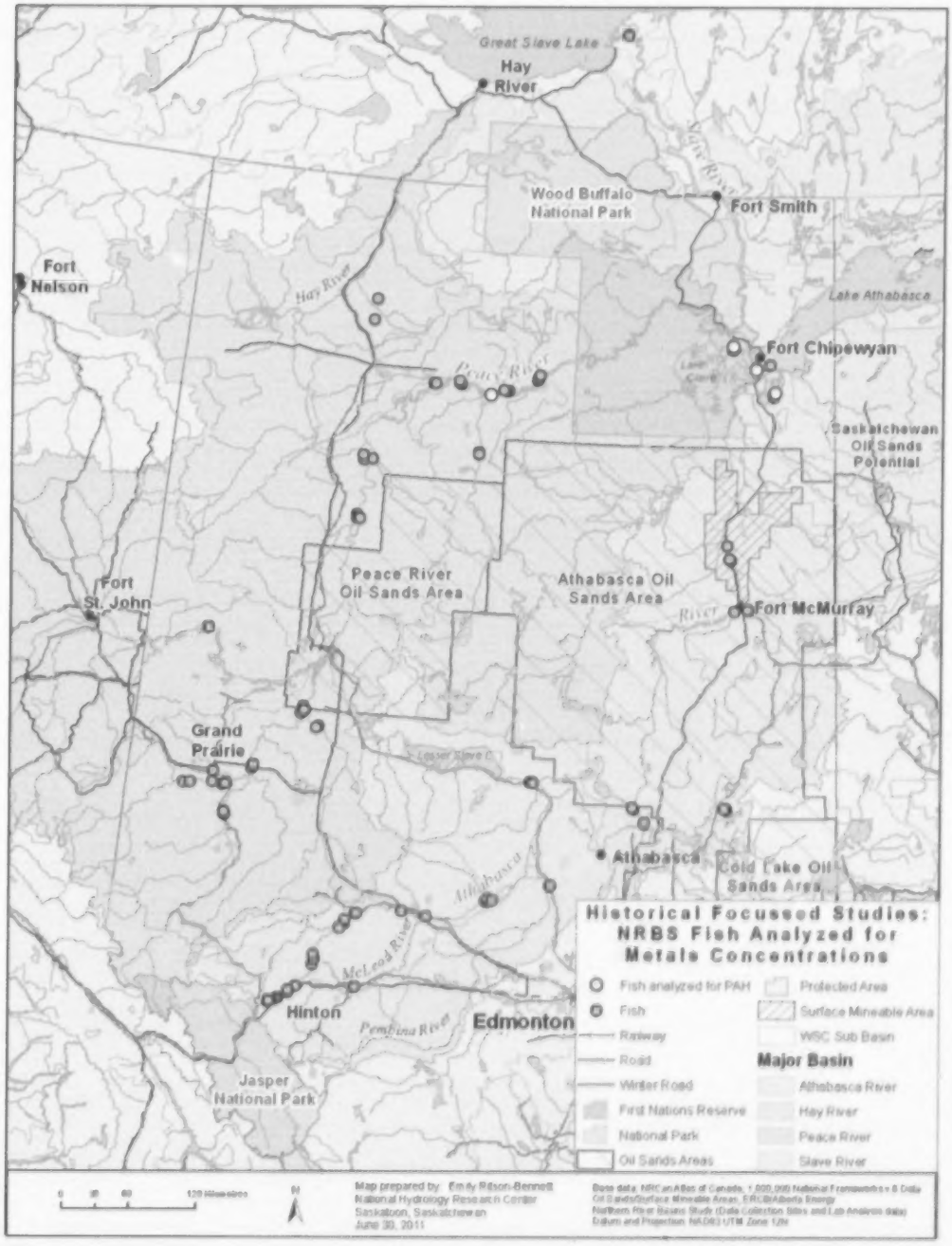


Figure 16: Historical monitoring of goldeye in the Peace-Athabasca Delta (Donald *et al.*, 2004).

Figure 17: Water Survey of Canada hydrometric stations on the Peace, Athabasca and Slave River basins historically used to estimate sediment loads.

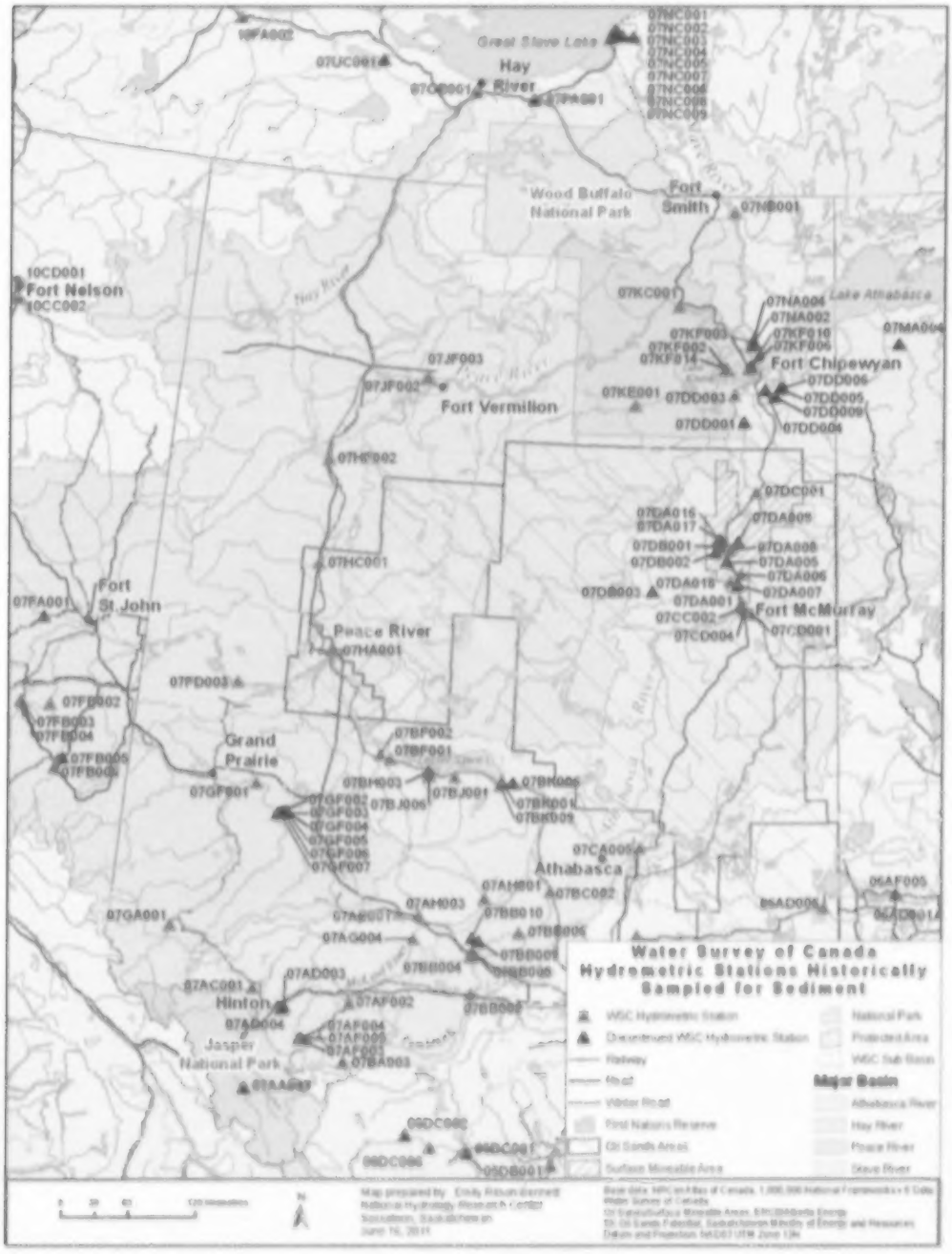
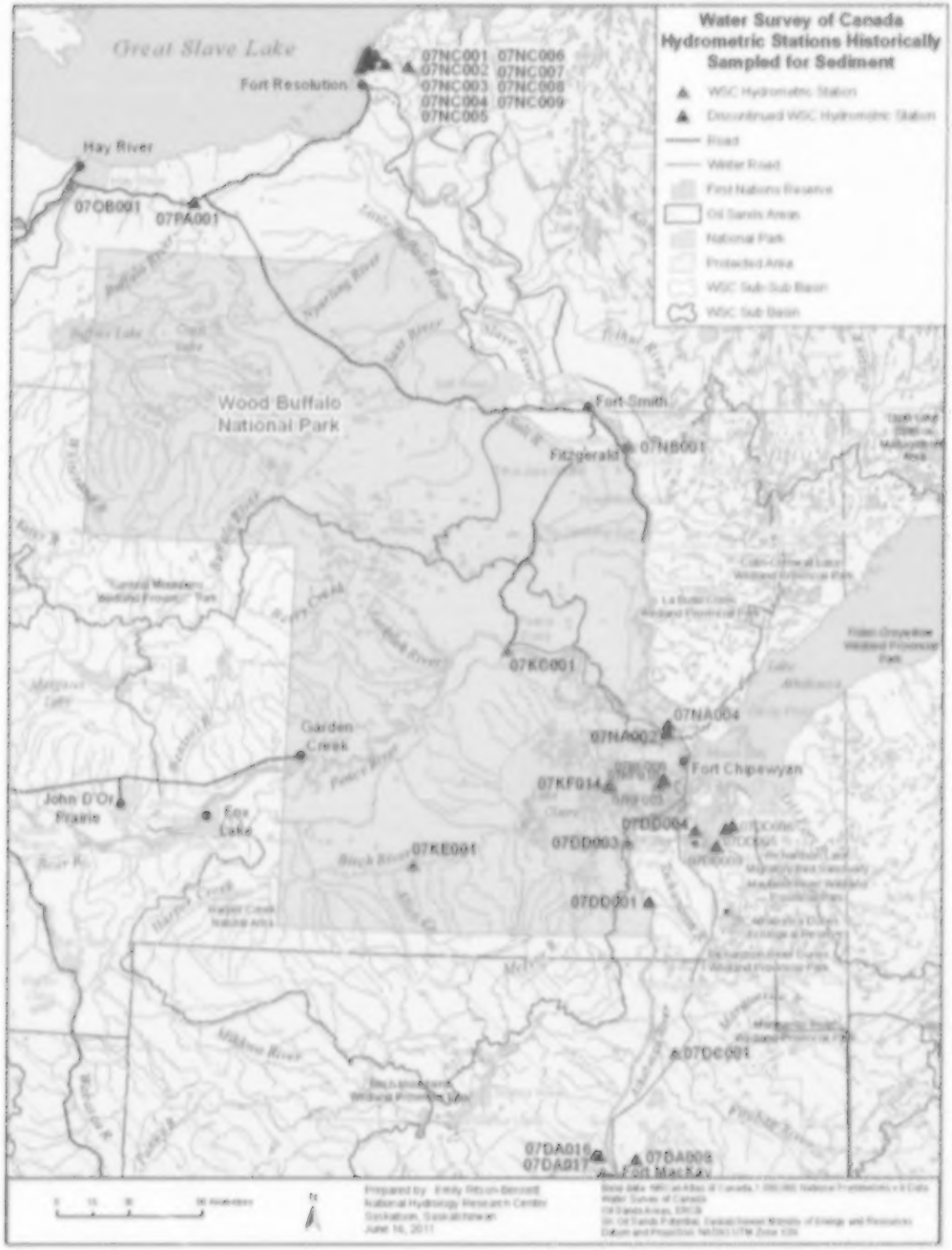


Figure 18: Water Survey of Canada hydrometric stations in the Expanded Geographic Extent historically used to estimate sediment loads.



APPENDIX 1: PARAMETERS SAMPLED BY LONG-TERM MONITORING PROGRAMS AND SELECTED FOCUSSED STUDIES

The following table includes specific information on parameters sampled by major monitoring programs and other activities in the Expanded Geographic Extent region.

Editors' note: **IMPORTANT!** Appendix 1 contents are historical information from **prior to** the Integrated Monitoring Plan for the Oil Sands, and the Joint Canada | Alberta Implementation Plan for Oil Sands Monitoring. Alberta Environment and Environment Canada parameter lists, sampling sites and frequencies will have differences that will take effect as the Implementation Plan proceeds.

Decision standards for inclusion/exclusion of documents in the Phase 2 Component 2, Expanded Geographic Extent Information Table are as follows.

Not included:

- Water/sediment quality-related documents that report sampling within the area of interest, but only for contaminants typically associated with pulp and paper mill effluent;
- Documents that discuss sampling programs within the area of interest but exclusively present data from previous studies/reports/programs (i.e., do not report new data);
- One-off hydrological measurements (e.g., flow, depth) taken during water/sediment quality and/or fish/benthic focussed studies;
- Databases;
- Documents that collect samples for contaminant analysis which are intended to be presented in subsequent (unreferenced) reports.

Included:

- Documents that present sampling locations within the area of interest (even if only 1 or 2 among a majority of externally located sites);
- Water quality modeling studies;
- Documents concerned with fish and/or benthic community composition. Those reporting fish length measurements, abundance and/or movement are included only if they also assess community composition.

Contractions used in the table:

AENV – LTRN: Alberta Environment Long-term River Network (see Figures 2-4).

EC: Environment Canada or Environment Canada/partner sites on the Athabasca, Peace and Slave Rivers (see Figures 2-4).

Environmental Effects Monitoring: the EEM program is described in section A.3.1 (see Figure 11).

RAMP: Regional Aquatics Monitoring Program, described in section A1.6 (see Figures 9 and 10).

Appendix 1: Information table on parameters sampled and general frequency of sampling for long-term monitoring programs, notable research, and other studies on water and sediment quality, hydrology, fish, and benthos in the Expanded Geographic Extent area. Symbols in the cells for each parameter indicate that parameter is sampled for that program or study. AOSERP, NRBS and NREI are identified by study number, so that the number(s) in a cell for a given parameter indicate the study number of a study which sampled that parameter. Cross-references for the study numbers are given in Sub-table A-1, below. Notes on parameter suites specific to one study or program only are also given below the table.

Parameters	Long-term Monitoring Programs: Water and Sediment Quality											
	AANDC [*Italics - only grab samples*; **Bold - only centrifugate samples**; ***Both - centr. + grab samples***]					AENV Lake Monitoring	AENV-LTRN	BC Env.	EEM	Environment Canada	RAMP	
	Regular Monitoring	Slave River Environmental Quality Monitoring Program (SREQMP)		SREQMP Follow-up Monitoring								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: [Monthly during open water, opportunistically during winter; total ~ 10x/year]; CENTRIFUGATE: [4x/year]	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
Metals (T - total; D-dissolved; E - extractable)												
Aluminum			T	T	T		TD	T	T	TD	TD	T
Antimony			T	T	T		TD	T		TD	TD	T
Arsenic	T	T	T	T	T		TD	T	T	TD	TD	T
Barium			T	T	T		TD	T		TD	TD	T
Beryllium			T	T	T		TD	T		TD	TD	T
Bismuth			T	T	T		TD	T		TD	TD	T
Boron			T	T	T		TD	T		TD	TD	
Cadmium	T	T	T	T	T		TD	TD	T	TD	TD	T
Chromium	T	T	T	T	T		TD	TD		TD	TD	T
Chromium hexavalent							T					
Cobalt	T	T	T	T	T		TD	T		TD	TD	T
Copper	T	T	T	T	T		TD	TD	T	TD	TD	T
Gallium										TD		
Iron	T	T	T	T	T		TD	TD	T	TD	TD	T
Lanthium										TD		
Lead	T	T	T	T	T		TD	TD	T	TD	TD	T
Lithium				T			TD			TD	TD	T
Manganese	T	T	T	T	T		TD	TD	T	TD	TD	T
Mercury	T	T	T	T	T		T	TD	T		TD	T
Molybdenum			T	T	T		TD	T	T	TD	TD	T
Nickel	T	T	T	T	T		TD	T	T	TD	TD	T

1 - Prior to 2006 = Annual sampling during first 3 years, thereafter 1x every 3 years for sites in watersheds with preexisting RAMP stations

Parameters	Long-term Monitoring Programs: Water and Sediment Quality										
	AANDC [*Italics - only grab samples*; **Bold - only centrifugate samples**; ***Both - centr. + grab samples***]					AENV Lake Monitoring	AENV-LTRN	BC Env.	EEM	Environment Canada	RAMP	
	Regular Monitoring	Slave River Environmental Quality Monitoring Program (SREQMP)		SREQMP Follow-up Monitoring								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: [Monthly during open water, opportunistically during winter; total ~ 10x/year]; CENTRIFUGATE: [4x/year]	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
Rubidium				T						TD		
Selenium		*T*	T	**T**	T		TD	T	T	TD	TD	T
Silver			T	**T**	T		TD	T		TD	TD	T
Strontium			T	**T**	T		TD	T		TD	TD	T
Thallium				**T**	T		TD	T		TD	TD	T
Thorium							TD				TD	
Tin			T	**T**	T		TD	T			TD	T
Titanium			T	**T**	T		TD	T			TD	T
Uranium				**T**	T		TD		T	TD	TD	T
Vanadium			T	**T**	T		TD	T		TD	TD	T
Zinc	T	*T*	T	***T***	T		TD	TD	T	TD	TD	T
Zirconium								T				
Heavy Metals												
Water/sediment quality modelling												
PAHs												
1-Methyl naphthalene							x			x		
3-Methyl chloranthrene							x			x		
2-Methyl naphthalene		x	x	x	x		x	x		x		
7,12-Dimethylbenz(a) anthracene							x			x		
Benzo(c) phenanthrene							x			x		

1 - Prior to 2006 = Annual sampling during first 3 years, thereafter 1x every 3 years for sites in watersheds with preexisting RAMP stations

Parameters	Long-term Monitoring Programs: Water and Sediment Quality											
	AANDC [*Italics - only grab samples*; **Bold - only centrifugate samples**; ***Both - centr. + grab samples***]					AENV Lake Monitoring	AENV-LTRN	BC Env.	EEM	Environment Canada	RAMP	
	Regular Monitoring	Slave River Environmental Quality Monitoring Program (SREQMP)		SREQMP Follow-up Monitoring								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: [Monthly during open water, opportunistically during winter; total ~ 10x/year]; CENTRIFUGATE: [4x/year]	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
Naphthalene		x	x	x	x		x	x		x	x	x
Acenaphthylene		x	x	x	x		x	x		x	x	x
Acenaphthene		x	x	x	x		x	x		x	x	x
Fluorene		x	x	x	x		x			x	x	x
Phenanthrene		x	x	x	x		x	x		x	x	x
Anthracene				x	x		x	x		x	x	x
Fluoranthene		x	x	x	x		x	x		x	x	x
Pyrene		x	x	x	x		x	x		x	x	x
Benz[a] anthracene				x	x		x	x		x	x	x
Chrysene				x	x		x	x		x	x	x
Benzo[b] fluoranthene		x	x	x	x		x	x		x	x	x
Benzo[j,k] fluoranthene				x	x		x	x		x	x	x
Benzo[e]pyrene							x			x		
Benzo[a]pyrene		x	x	x	x		x	x		x	x	x
Dibenzo[AH] pyrene							x			x		
Dibenzo[AI] pyrene							x			x		
Dibenzo[AL] pyrene							x			x		
Perylene		x	x	x	x		x			x		
Dibenzo[a,h] anthracene		x	x	x	x		x	x		x	x	x
Indeno[1,2,3-c,d]- pyrene		x	x	x	x		x	x		x	x	x

1 - Prior to 2006 = Annual sampling during first 3 years, thereafter 1x every 3 years for sites in watersheds with preexisting RAMP stations

	Long-term Monitoring Programs: Water and Sediment Quality										
Parameters	**AANDC** *[Italics - only grab samples;* **Bold - only centrifugate samples;** ***Both - centr. + grab samples]***					**AENV Lake Monitoring**	**AENV-LTRN**	**BC Env.**	**EEM**	**Environment Canada**	**RAMP**	
	Regular Monitoring	**Slave River Environmental Quality Monitoring Program (SREQMP)**		**SREQMP Follow-up Monitoring**								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: [Monthly during open water, opportunistically during winter; total ~ 10x/year]; CENTRIFUGATE: [4x/year]	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4 x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
Benzo(g,h,i) perylene		x	x	x	x		x	x		x	x	x
Acridine										x		
Methyl Acenaphthene				x	x						x	x
Biphenyl				x	x						x	x
Retene							x			x	x	x
Dibenzo thiophene				x	x						x	x
Methyl-Biphenyl				x	x						x	x
Dimethyl-Biphenyl											x	x
C1-Benzo fluoranthene/ Benzopyrenes											x	x
C2-Benzo fluoranthene/ Benzopyrenes				x	x						x	x
C2-Fluoranthene/Pyrenes												x
C3-Fluoranthene/Pyrenes												x
C1-Naphthalenes											x	x
C2-Naphthalenes				x	x						x	x
C3-Naphthalenes				x	x						x	x

1 - Prior to 2006 = Annual sampling during first 3 years, thereafter 1x every 3 years for sites in watersheds with preexisting RAMP stations

Parameters	Long-term Monitoring Programs: Water and Sediment Quality											
	AANDC [*Italics - only grab samples*; **Bold - only centrifugate samples**; ***Both - centr. + grab samples***]					AENV Lake Monitoring	AENV-LTRN	DC Env.	EEM	Environment Canada	RAMP	
	Regular Monitoring	Slave River Environmental Quality Monitoring Program (SREQMP)		SREQMP Follow-up Monitoring								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: [Monthly during open water, opportunistically during winter; total ~ 10x/year]; CENTRIFUGATE: [4x/year]	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
C4-Naphthalenes				x	x						x	x
C1-Fluorenes											x	x
C2-Fluorenes				x	x						x	x
C3-Fluorenes												x
C4-Fluorenes												
C1-Dibenzo thiophene											x	x
C2-Dibenzo thiophenes				x	x						x	x
C3-Dibenzo thiophenes				x	x						x	x
C4-Dibenzo thiophenes				x	x						x	x
C1-Phenanthrenes/ Anthracenes											x	x
C2-Phenanthrenes/ Anthracenes				x	x						x	x
C3-Phenanthrenes/ Anthracenes				x	x						x	x
C4-Phenanthrenes/ Anthracenes				x	x						x	x
C1-Fluoranthenes/ Pyrenes											x	x

1 - Prior to 2006 = Annual sampling during first 3 years, thereafter 1x every 3 years for sites in watersheds with preexisting RAMP stations

Parameters	Long-term Monitoring Programs: Water and Sediment Quality										
	AANDC (*Italics - only grab samples*; **Bold - only centrifugate samples**; ***Both - centr. + grab samples***)					AENV Lake Monitoring	AENV-LTRN	BC Env.	EEM	Environment Canada	RAMP	
	Regular Monitoring	Slave River Environmental Quality Monitoring Program (SREQMP)		SREQMP Follow-up Monitoring								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: [Monthly during open water, opportunistically during winter; total ~ 10x/year]; CENTRIFUGATE: [4x/year]	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
C2-Fluoranthenes/ Pyrenes												x
C3-Fluoranthenes/ Pyrenes												x
C4-Fluoranthenes/ Pyrenes												
C1-Benz[a] anthracenes/ Chrysenes											x	x
C2-Benz[a] anthracenes/ Chrysenes				x	x		x				x	x
C1-Chrysene												
C2-Chrysene												
C3-Chrysene												
C4-Chrysene												
Naphthenic Acids											x	
total							x			x	x	
Nutrients												
DOC				x		x	x		x	x	x	
DIC											x	
TOC			x	x	x		x	x	x	x	x	x
POC												
DKN												

1 - Prior to 2006 = Annual sampling during first 3 years, thereafter 1x every 3 years for sites in watersheds with preexisting RAMP stations

Parameters	Long-term Monitoring Programs: Water and Sediment Quality											
	AANDC (*Italics - only grab samples*; **Bold - only centrifugate samples**; ***Both - centr. + grab samples***)					AENV Lake Monitoring	AENV-LTRN	BC Env.	EEM	Environment Canada	RAMP	
	Regular Monitoring	Slave River Environmental Quality Monitoring Program (SREQMP)		SREQMP Follow-up Monitoring								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: (Monthly during open water, opportunistically during winter; total ~ 10x/year); CENTRIFUGATE: (4x/year)	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
TKN	x			x		x	x	x		x	x	
DON												
PON												
TDN										x	x	
TN							x	x		x	x	
TIN												
NH_3												
Ammonia-N	x	x					x			x	x	
Nitrate + nitrite	x	x		x		x		x		x	x	
Chlorophyll a						x	x			x	x	
SRP												
TP	x	x	x	x	x	x	x	x	x	x	x	x
TDP		x		x		x	x			x	x	
Reactive Silica				x			x	x		x		
Major Ions												
Calcium	x	x	x	x	x	x	x	x	x	x	x	x
Potassium	x	x	x	x	x	x	x	x	x	x	x	x
Magnesium	x	x	x	x	x	x	x	x	x	x	x	x
Sodium	x	x	x	x	x	x	x	x	x	x	x	x
Sulphide		x		x						x	x	
Sulphate	x	x		x		x	x	x	x	x	x	
Chloride	x	x		x		x	x	x	x	x	x	
Fluoride				x		x		x	x			
Silicon											x	
Hardness	x	x		x		x	x	x	x	x	x	

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Parameters	Long-term Monitoring Programs: Water and Sediment Quality											
	AANDC [*Italics - only grab samples*; **Bold - only centrifugate samples**; ***Both - centr. + grab samples***]					AENV Lake Monitoring	AENV-LTRN	BC Env.	EEM	Environment Canada	RAMP	
	Regular Monitoring	Slave River Environmental Quality Monitoring Program (SREQMP)		SREQMP Follow-up Monitoring								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: [Monthly during open water, opportunistically during winter; total ~ 10x/year]; CENTRIFUGATE: [4x/year]	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
Alkalinity	x	x		x		x	x	x	x	x	x	
Bicarbonate						x	x			x	x	
Physicals												
Conductivity/ conductance	x	x		x		x	x		x	x	x	
pH	x	x		x		x	x	x	x	x	x	
Temperature				x			x	x	x	x		
Turbidity	x	x		x			x	x		x	x	
TDS	x	x		x		x	x	x		x	x	
TSS	x	x		x			x	x	x	x	x	
BOD		x		x			x			x	x	
Colour	x	x		x			x	x		x	x	
Petroleum Hydrocarbons (BTEX)												
Benzene							x			x		x
Toluene							x			x		x
Ethylene							x			x		x
Xylene							x			x		x
CCME 4-fraction petroleum hydrocarbons							x (since 2008)					
F1 (C6-C10)										x		x
F2 (C10-C16)										x		x
F3 (C16-C34)										x		x
F4 (C34-C50)										x		x

1 - Prior to 2006 = Annual sampling during first 3 years, thereafter 1x every 3 years for sites in watersheds with preexisting RAMP stations

Parameters	Long-term Monitoring Programs: Water and Sediment Quality											
	AANDC [*Italics - only grab samples*; **Bold - only centrifugate samples**; ***Both - centr. + grab samples***]					AENV Lake Monitoring	AENV-LTRN	BC Env.	EEM	Environment Canada	RAMP	
	Regular Monitoring	Slave River Environmental Quality Monitoring Program (SREQMP)		SREQMP Follow-up Monitoring								
Focus	Water	Water	Sediment	Water	Sediment	Water	Water	Water	Water	Water	Water	Sediment
Reference(s); (see sub-tables A.1 and A.2 for cross references)		Sanderson *et al.*, 1997	Sanderson *et al.*, 1997	Sanderson *et al.*, (in prep)	Sanderson *et al.*, (in prep)	A	A	B	Environment Canada 2010; 2007; Lowell *et al.*, 2005		RAMP 2011; 2009; 2004	RAMP 2011; 2009
Greater than 5 years of data in program	Yes (1982-present)	Yes (1990-1995)	Yes (1990-1995)	Yes (2001-2003; 2006-2007)	Yes (2001-2003; 2006-2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
General frequency of sampling	2x/year	GRAB: [Monthly during open water, opportunistically during winter; total ~ 10x/year]; CENTRIFUGATE: [4x/year]	4x/year	GRAB: [3-4 x/year]; CENTRIFUGATE [3-4x/year]	3-4 x/year	Monthly during open water	Monthly	Variable	4x/year	Monthly	Seasonal sampling during first 3 years at a new site, then once per year in Fall with limited seasonal sampling for various sites	2006-present = sampled in conjunction with benthic invertebrate schedule[1]
Oil and Grease												
colourimetric												
gravimetric												
Cyanide							x		x	x		
Other organics, including pesticides (varies by project or program)		**Note 1a**	Note 1b	**Note 2a**	Note 2b		Note 3					

1 - Prior to 2006 = Annual sampling during first 3 years, thereafter 1x every 3 years for sites in watersheds with preexisting RAMP stations

	Monitoring Programs and Research Studies: Water and Sediment Quality					Research and Monitoring Studies: Water and Sediment Quality										
Parameters	**AOSERP**		**NRBS**		**NREI**	**Summers (1978)**	**Noton and Shaw (1989)**	**Shaw *et al.* (1990)**	**Evans *et al.*, (1998a)**		**Stone and English (1998)**	**Milburn *et al.* (2000)**	**Evans *et al.* (2005)**	**Pawlisky and Smith (2009)**	**Kelly et al. (2009, 2010)**	**Sokal *et al.*, 2010**
Focus	Water	Sediment	Water	Sediment	Sediment	Water	Water	Water	Water	Sediment	Sediment	Sediment	Water	Water	Water	Water
Reference(s); see tables A.1 & A.2 for cross-references)	17 / 123 / 71 / L-74 / L-85	17 / 34 / 123	112 / 131	71 / 72 / 99 / 106 / 134 / 135 / 136	26											
Greater than 5 years of data in program																
General frequency of sampling	Varies by project	Varies by project	Varies by project	Varies by project	2x (1997)		5x (1988-1989)	7x (1988-1989)			3x (1996-1997)			1-25x/2 years, depending on site		3-10x (2003-2005)
Metals (T - total; D-dissolved; E - extractable)																
Aluminum	L-85[E]	34		99			E	TD		T	T	T				
Antimony											T				TD	
Arsenic	17, L-85[TD]	17, 34		72, 99, 135	26		T	TD	TD	T	T	T			TD	
Barium		34						TD			T					
Beryllium		34					E	TD							TD	
Bismuth											T					
Boron	L-85[TD]							TD								
Cadmium	17, L-85[E], L-74[E]	17		72, 99, 135	26		T	TD	TD	T	T	T			TD	
Chromium	17, L-74[E]	17, 34		72, 99, 135	26		T	TD	TD	T	T	T			TD	
Chromium hexavalent	L-85						TD									
Cobalt	L-85[E], L-74[E]	34			26		T	TD			T					
Copper	17, L-85[E], L-74[E]	17, 34		72, 99, 135			T	TD	TD	T	T	T			TD	
Gallium																
Iron	17, L-85[E], 71, L-74[E]	17, 34		99			E	TD	TD	T	T	T				
Lanthium																
Lead	17, L-85[E], L-74[E]	17, 34		72, 99, 135	26		T	TD	TD	T	T	T			TD	
Lithium																
Manganese	17, L-85[E], 71, L-74[E]	17, 34		99	26		T	TD	TD	T	T	T				

	Monitoring Programs and Research Studies: Water and Sediment Quality					Research and Monitoring Studies: Water and Sediment Quality										
Parameters	**AOSERP**		**NRBS**		**NREI**	**Summers (1978)**	**Noton and Shaw (1989)**	**Shaw *et al.* (1990)**	**Evans *et al.*, (1998a)**		**Stone and English (1998)**	**Milburn *et al.* (2000)**	**Evans *et al.* (2005)**	**Pavelsky and Smith (2009)**	**Kelly et al. (2009, 2010)**	**Sokal *et al.*, 2010**
Focus	Water	Sediment	Water	Sediment	Sediment	Water	Water	Water	Water	Sedim ent	Sediment	Sediment	Water	Water	Water	Water
Reference(s); see tables A.1 & A.2 for cross-references)	17 / 123 / 71 / L-74 / L-85	17 / 34 / 123	112 / 131	71 / 72 / 99 / 106 / 134 / 135 / 136	26											
Greater than 5 years of data in program																
General frequency of sampling	Varies by project	Varies by project	Varies by project	Varies by project	2x (1997)		5x (1988-1989)	7x (1988-1989)			3x (1996-1997)			1-25x/2 years, depending on site		3-10x (2003-2005)
Mercury	17, L-85[T], L-74[E]	17, 34		71, 72, 99, 106	26		T	T		T	T	T	T		TD	
Molybdenum							T	TD								
Nickel	17, L-85[E], L-74[E]	17, 34		99, 135	26		T	TD	TD	T	T				TD	
Rubidium											T					
Selenium	L-85[TD]	17		99			T	TD		T					TD	
Silver	L-85[E]							TD			T				TD	
Strontium		34									T					
Thallium											T				TD	
Thorium											T					
Tin											T					
Titanium		34									T	T				
Uranium											T					
Vanadium	17, L-85[T]	17, 34		72, 99			T	TD	TD	T	T					
Zinc	17, L-85[E], L-74[E]	17, 34		72, 99, 135	26		T	TD	TD	T	T				TD	
Zirconium											T					
Heavy Metals																
Water/sediment quality modelling			112	#												
PAHs																
1-Methyl naphthalene				72, 99												
3-Methyl chloranthrene				99												
2-Methyl naphthalene				72												
7,12-Dimethylbenz (a)anthracene																

	Monitoring Programs and Research Studies: Water and Sediment Quality					Research and Monitoring Studies: Water and Sediment Quality										
Parameters	**AOSERP**		**NRBS**		**NREI**	**Summers (1978)**	**Noton and Shaw (1989)**	**Shaw *et al.* (1990)**	**Evans *et al.*, (1998a)**		**Stone and English (1998)**	**Milburn *et al.* (2000)**	**Evans *et al.* (2005)**	**Pavelsky and Smith (2009)**	**Kelly et al. (2009, 2010)**	**Sokal *et al.*, 2010**
Focus	Water	Sediment	Water	Sediment	Sediment	Water	Water	Water	Water	Sediment	Sediment	Sediment	Water	Water	Water	Water
Reference(s); see tables A.1 & A.2 for cross-references)	17 / 123 / 71 / L-74 / L-86	17 / 34 / 123	112 / 131	71 / 72 / 99 / 106 / 134 / 135 / 138	26											
Greater than 5 years of data in program																
General frequency of sampling	Varies by project	Varies by project	Varies by project	Varies by project	2x (1997)		5x (1988-1989)	7x (1988-1989)			3x (1996-1997)			1-25x/2 years, depending on site		3-10x (2003-2005)
Benzo(c) phenanthrene																
Naphthalene				72, 99, 106, 134	26		x	x							x	
Acenaphthylene				99, 106			x	x							x	
Acenaphthene				99, 106	26		x	x							x	
Fluorene				72, 99, 106	26		x	x							x	
Phenanthrene				72, 99, 106, 134	26		x	x							x	
Anthracene				99, 106			x	x							x	
Fluoranthene				72, 99, 106, 134	26		x	x							x	
Pyrene				72, 99, 106, 134	26		x	x							x	
Benz[a] anthracene				99, 106, 134			x	x							x	
Chrysene				99, 106, 134			x	x							x	
Benzo[b] fluoranthene				72, 99, 106, 134	26		x	x							x	
Benzo[j, k] fluoranthene				72, 99, 106	26		x	x							x	
Benzo[e]pyrene				99, 106												
Benzo[a]pyrene				72, 99, 106, 134	26		x	x							x	
Dibenzo[a,h] pyrene																
Dibenzo[a,i] pyrene																
Dibenzo[a,l] pyrene																
Perylene				99, 106	26		x	x								
Dibenzo[a,h] anthracene				99, 106, 134	26		x	x							x	
Indeno[1,2,3-c,d]- pyrene				99, 106, 134	26		x	x							x	
Benzo[g,h,i] perylene				72, 99, 106, 134	26		x	x							x	

	Monitoring Programs and Research Studies: Water and Sediment Quality					Research and Monitoring Studies: Water and Sediment Quality										
Parameters	**AOSERP**		**NRBS**		**NREI**	**Summers (1978)**	**Noton and Shaw (1980)**	**Shaw et al. (1980)**	**Evans et al., (1998a)**		**[redacted] and English (1998)**	**Milburn et al. (2000)**	**Evans et al. (2000)**	**Pavelsky and Smith (2009)**	**Kelly et al. (2009, 2010)**	**Sokal et al., 2010**
Focus	Water	Sediment	Water	Sediment	Sediment	Water	Water	Water	Water	Sediment	Sediment[redacted]	Sediment	Water	Water	Water	Water
Reference(s); see tables A.1 & A.2 for cross-references)	17 / 123 / 71 / L-74 / L-85	17 / 34 / 123	112 / 131	71 / 72 / 99 / 106 / 134 / 135 / 136	26											
Greater than 5 years of data in program																
General frequency of sampling	Varies by project	Varies by project	Varies by project	Varies by project	2x (1997)		5x (1988-1989)	7x (1988-1989)			3x (1996-1997)			1-25x/2 years, depending on site		8-10x (2003-2005)
Acridine																
Methyl Acenaphthene															x	
Biphenyl																
Retene				99, 106											x	
Dibenzo pthiophene				99, 106												
Methyl-Biphenyl																
Dimethyl-Biphenyl																
C1-Benzo fluoranthene/ Benzopyrenes																
C2-Benzo fluoranthene/ Benzopyrenes																
C2-Fluoranthene/Pyrenes																
C3-Fluoranthene/Pyrenes																
C1-Naphthalenes				106											x	
C2-Naphthalenes				106											x	
C3-Naphthalenes				106											x	
C4-Naphthalenes				106											x	
C1-Fluorenes															x	
C2-Fluorenes															x	
C3-Fluorenes															x	
C4-Fluorenes															x	
C1-Dibenzo pthiophene				106											x	
C2-Dibenzo pthiophenes				106											x	

	Monitoring Programs and Research Studies: Water and Sediment Quality					Research and Monitoring Studies: Water and Sediment Quality										
Parameters	**AOSERP**		**NRBS**		**NREI**	**Summers (1970)**	**Noton and Shaw (1989)**	**Shaw et al. (1990)**	**Evans et al., (1998a)**		**Blone and English (1998)**	**Milburn et al. (2000)**	**Evans et al. (2005)**	**Pavelsky and Smith (2009)**	**Kelly et al. (2009, 2010)**	**Sokal et al., 2010**
Focus	Water	Sediment	Water	Sediment	Sediment	Water	Water	Water	Water	Sediment	Sediment	Sediment	Water	Water	Water	Water
Reference(s); see tables A.1 & A.2 for cross-references)	17 / 123 / 71 / L-74 / L-85	17 / 34 / 123	112 / 131	71 / 72 / 99 / 106 / 134 / 135 / 136	28											
Greater than 5 years of data in program																
General frequency of sampling	Varies by project	Varies by project	Varies by project	Varies by project	2x (1997)		8x (1988-1989)	7x (1988-1989)			3x (1996-1997)			1-25x/2 years, depending on site		3-10x (2003-2005)
C3-Dibenzo pthiophenes															x	
C4-Dibenzo pthiophenes															x	
C1-Phenanthrenes/ Anthracenes															x	
C2-Phenanthrenes/ Anthracenes															x	
C3-Phenanthrenes/ Anthracenes															x	
C4-Phenanthrenes/ Anthracenes															x	
C1-Fluoranthenes/ Pyrenes				106											x	
C2-Fluoranthenes/ Pyrenes				106											x	
C3-Fluoranthenes/ Pyrenes				106											x	
C4-Fluoranthenes/ Pyrenes				106											x	
C1-Benz[a] anthracenes/ Chrysenes																
C2-Benz[a] anthracenes/ Chrysenes																
C1-Chrysene															x	
C2-Chrysene															x	
C3-Chrysene															x	
C4-Chrysene															x	

	Monitoring Programs and Research Studies: Water and Sediment Quality					Research and Monitoring Studies: Water and Sediment Quality										
Parameters	**AOSERP**		**NRBS**		**NREI**	**Summers (1978)**	**Noton and Shaw (1989)**	**Shaw *et al.* (1990)**	**Evans *et al.*, (1996a)**		**Stone and English (1998)**	**Milburn *et al.* (2000)**	**Evans *et al.* (2005)**	**Pavelsky and Smith (2009)**	**Kelly et al. (2009, 2010)**	**Sokal *et al.*, 2010**
Focus	Water	Sediment	Water	Sediment	Sediment	Water	Water	Water	Water	Sediment	Sediment	Sediment	Water	Water	Water	Water
Reference(s); see tables A.1 & A.2 for cross-references)	17 / 123 / 71 / L-74 / L-85	17 / 34 / 123	112 / 131	71 / 72 / 99 / 106 / 134 / 135 / 136	28											
Greater than 5 years of data in program																
General frequency of sampling	Varies by project	Varies by project	Varies by project	Varies by project	2x (1997)		5x (1988-1989)	7x (1988-1989)			3x (1996-1997)			1-25x/2 years, depending on site		3-10x (2003-2005)
Naphthenic Acids																
Inital																
Nutrients																
DOC			131				x	x					x			x
DIC	71						x									
TOC		34		71, 72, 99, 135				x								
POC			131						x							
DKN																
TKN	L-74	34		#			x	x								x
DON																
PON			131						x							
TDN	71							x								
TN																
TIN																
NH_4																
Ammonia-N	71						x	x	x							
Nitrate + nitrite	71		131			x	x	x	x							
Chlorophyll a	71, L-74		131						x							x
SRP																
TP			131	#			x	x	x		x	x				x
TDP	71		131					x	x							x
Reactive Silica	L-85, L-74					x	x	x	x							x
Major Ions																
Calcium	L-85, 71, L-74	34				x	x	x			x	x				x
Potassium	123, L-85, 71, L-74						x	x			x	x				x
Magnesium	123, L-85, 71, L-74	34					x	x			x	x				x

	Monitoring Programs and Research Studies: Water and Sediment Quality					Research and Monitoring Studies: Water and Sediment Quality										
Parameters	**AOSERP**		**NRBS**		**NREI**	**Summers (1978)**	**Noton and Shaw (1989)**	**Shaw *et al.* (1990)**	**Evans *et al.*, (1998a)**		**Stone and English (1998)**	**Milburn *et al.* (2000)**	**Evans *et al.* (2005)**	**Pavelsky and Smith (2009)**	**Kelly et al. (2009, 2010)**	**Sokal *et al.*, 2010**
Focus	Water	Sediment	Water	Sediment	Sediment	Water	Water	Water	Water	Sediment	Sediment	Sediment	Water	Water	Water	Water
Reference(s); see tables A.1 & A.2 for cross-references)	17 / 123 / 71 / L-74 / L-85	17 / 34 / 123	112 / 131	71 / 72 / 99 / 106 / 134 / 135 / 136	26											
Greater than 5 years of data in program																
General frequency of sampling	Varies by project	Varies by project	Varies by project	Varies by project	2x (1997)		5x (1988-1989)	7x (1988-1989)			3x (1996-1997)			1-25x/2 years, depending on site		3-10x (2003-2005)
Sodium	123, L-85, 71, L-74	34						x			x	x				x
Sulphide																
Sulphate	123, L-85, 71, L-74					x	x	x								x
Chloride	123, L-85, 71, L-74					x	x	x			x					x
Fluoride	L-85, L-74						x	x			x					
Silicon	71										x	x				
Hardness	L-85, L-74					x	x	x								
Alkalinity	L-85, 71, L-74					x	x	x								x
Bicarbonate	123, L-85						x	x								
Physicals																
Conductivity/ conductance	123, L-85, L-74		131				x	x	x				x	x		x
pH	123, L-85, 71, L-74		131			x	x	x	x				x			x
Temperature	123, L-85, 71		131			x	x	x	x				x	x		x
Turbidity	123, L-85, L-74					x		x	x					x		
TDS	L-74						x	x								
TSS	123, L-85, L-74							x	x					x		
BOD							x	x								
Colour	71, L-74					x	x	x								
Petroleum Hydrocarbons (BTEX)																
Benzene							x									

	Monitoring Programs and Research Studies: Water and Sediment Quality					Research and Monitoring Studies: Water and Sediment Quality									
Parameters	**AOSERP**		**NRBS**		**NREI**	**Summers (1978)**	**Noton and Shaw (1989)**	**Shaw *et al.* (1990)**	**Evans *et al.*, (1998a)**		**Stone and English (1998)**	**Milburn *et al.* (2000)**	**Evans *et al.* (2005)**	**Pavelsky and Smith (2009)**	**Kelly et al. (2009, 2010)**	**Sokal *et al.*, 2010**
Focus	Water	Sediment	Water	Sediment	Sediment	Water	Water	Water	Water	Sediment	Sediment	Sediment	Water	Water	Water	Water
Reference(s); see tables A.1 & A.2 for cross-references)	17 / 123 / 71 / L-74 / L-85	17 / 34 / 123	112 / 131	71 / 72 / 99 / 108 / 134 / 135 / 136	26											
Greater than 5 years of data in program																
General frequency of sampling	Varies by project	Varies by project	Varies by project	Varies by project	2x (1997)		5x (1988-1989)	7x (1988-1989)			3x (1996-1997)			1-25x/2 years, depending on site		3-10x (2003-2005)
Toluene							x									
Ethylene																
Xylene																
F1 (C6-C10)				72												
F2 (C10-C16)				72												
F3 (C16-C34)				72												
F4 (C34-C50)				72												
Oil and Grease																
colourimetric	L-85, L-74						x	x								
gravimetric																
Cyanide								x								
Other organics, including pesticides (varies)				Notes 4, 5, 6 and 7	Note 8		Note 9									

	Long-term Monitoring Programs: Hydrology						Monitoring Programs and Research Studies: Hydrology			Research and Monitoring Studies: Hydrology				
Parameters	**AANDC**	**AENV**	**AENV / EC Water Survey of Canada**	**BC Env.**	**BC Hydro**	**RAMP**	**AOSERP**	**NRBS**	**NREI**	**Prowse and Conly (1998)**	**Leconte *et al.* (2006)**	**Pavelsky and Smith (2009)**	**Beltaos (2008, 2007, 2003); Beltaos and Carter (2009); Beltaos *et al.* (2006)**	**Andrishak and Hicks (2011)**
Reference(s); see tables A.1 & A.2 for cross-references)	C	D	E	F	G	RAMP, 2011; 2009	60 / 123 / 40 / 18	43 / 74 / 76 / 77 / 102 / 103 / 122 / 146	17 / 26					
Greater than 5 years of data in program	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes					
General frequency of sampling	Annually	Monthly in the winter spring (manual) + near-real time (automated)	Near-real time (automated)	8x/year + near-real time (automated)	Near-real time (automated)	Snow survey = 3x/winter; Flow and water level = 10x/year (manual) + near-real time (automated)	Varies by project	Varies by project	Varies by project			1-25x/2 years (manual) + near-real time (automated)		
Hydrologic monitoring, flow			x		x	x	60, 40, 18		26			x		
Hydrologic monitoring, water level		x	x		x	x	18		26			x		
Ice & ice-jam flood processes								74, 103, 122, 146	17	x	x		2003, 2006, 2007, 2008, 2009	x
Flow regulation effects							123	43, 74, 77, 102, 103, 122, 146	17, 26	x			2006	
Hydrologic modelling								43, 76, 77, 103, 122	17	x	x		2003, 2006, 2007, 2008, 2009	x
Snow depth measurements	x	x		x		x								

Parameters		Long-term Monitoring Programs: Biological				Monitoring Programs and Research Studies: Biological		
		AANDC		EEM	RAMP	AOSERP	NRBS	NREI
		Fort Resolution Fish Monitoring Program	Slave River Environmental Quality Monitoring Program (SREQMP)					
Reference(s); see tables A.1 & A.2 for cross-references)		Lafontaine (1997)	McCarthy *et al.* (1997), Sanderson *et al.* (1997)	Environment Canada (2010, 2007); Lowell *et al.* (2005)	RAMP (2011, 2009)	2 / 17 / 89	9 / 20 / 26 / 61 / 74 / 119 / 135	18
Greater than 5 years of data in program		No (1992-1993)	Yes (1990-1995)	Yes	Yes	Yes	Yes	Yes
General frequency of sampling		83 fish sampled (1992-1993)	2x/year (open water + under ice)	Once every 2-6 years, depending on program	Fish = Annual monitoring, though activities are spatially and temporally variable; Benthos = Annual baseline sampling for first 3 years, thereafter frequency dependent upon demand/intensity of local oil sand operations	Varies by project	Varies by project	
Fish								
Measurement (length)		x	x	x	x	2, 89	9, 20, 26, 61, 118	
Population data by species						2, 89	9, 61, 118	
Community composition				x		89	119	
Tissue contaminants	Metals	x	x			17		
	Radionuclides						26	
	Mercury	x	x	x	x	17		
	CPs		x					
	OCPs		x			17		
	PCBs		x			17		
	PCDDs/PCDFs		x	x				
	PAHs		x					
Endocrine disruption				x				
Movement and habitat use						2, 89	9	
Benthic invertebrates								
Community composition			x	x	x			
Ecotoxicity tests				x	x		135	
Tissue contaminants	Metals					17		
	Radionuclides							
	Mercury							
	CPs							
	OCPs							
	PCBs							
	PCDDs/PCDFs							
	PAHs							
Vegetation								
Vegetation surveys					x		74	18

		Research and Monitoring Studies: Biological									
Parameters		**Donald and Kooyman (1977b)**	**Summers (1978)**	**Kristensen (1981); Kristensen and Summers (1981)**	**McCart *et al.* (1982)**	**Shaw *et al.* (1990)**	**Evans *et al.* (1998a)**	**Tetreault *et al.* (2003)**	**Evans *et al.* (2005)**	**Fort Chipewyan First Nation and CNRL (2006)**	**Donald and Sardella (2010)**
Reference(s); (see tables A2.1 & A2.2 for cross references)										Hatfield Consultants Ltd. (2006)	
Greater than 5 years of data in program											
General frequency of sampling		4,375 fish sampled (1972-1975)		9,906 fish sampled (1976-1977)		7x (1988-1989)		481 fish sampled (1999-2000)		116 fish sampled (2005)	80 fish sampled (2002-2005)
Fish											
Measurement (length)		x	x	x	x		x	x	x	x	
Population data by species		x	x	x	x						
Community composition										x	
Tissue contaminants	Metals								x	x	
	Radionuclides									x	
	Mercury								x	x	x
	CPs										
	OCPs										
	PCBs										
	PCDDs/PCDFs										
	PAHs										
Endocrine disruption								x			
Movement and habitat use		x	x	x	x						
Benthic invertebrates											
Community composition						x					
Ecotoxicity tests											
Tissue contaminants	Metals										
	Radionuclides										
	Mercury										
	CPs										
	OCPs										
	PCBs										
	PCDDs/PCDFs										
	PAHs										
Vegetation											
Vegetation surveys				x							

Note 1a: SREQMP – Centrifugate Water Parameters Analyzed

2-chlorophenol, 4-chlorophenol, 2,4-dichlorophenol, 2,6-dichlorophenol, 2,4,5-trichlorophenol, 2,4,6-trichlorophenol, 2,3,4,6-tetrachlorophenol, pentachlorophenol, 2,4-dimethylphenol, 2-nitrophenol, 4,-nitrophenol, 2,4-dinitrophenol, 2-methyl-4,6-dinitrophenol, 4-chlorocatechol, 3,4-dichlorocatechol, 3,5-dichlorocatechol, 3,6-dichlorocatechol, 4,5-dichlorocatechol, 3,4,5-trichlorocatechol, 3,4,6-trichlorocatechol, tetrachlorocatechol, 4-chloroguaiacol, 5-chloroguaiacol, 6-chloroguaiacol, 3,4,-dichloroguaiacol, 4,5-dichloroguaiacol, 4,6-dichloroguaiacol, 3,4,5-trichloroguaiacol, 3,4,6-trichloroguaiacol, 4,5,6-trichloroguaiacol, tetrachloroguaiacol, 4,5-dichloroveratrole, 3,4,5-trichloroveratrole, tetrachloroveratrole, 5-chlorovanillin, 6-chlorovanillin, 5,6-dichlorovanillin, 4,5,6-trichlorosyringol, 2,6-dichlorosyringaldehyde, 2-chlorosyringaldehyde, 4,5,6-trichlorotrimethoxybenzene, 1,1-dichlorodimethylsulfone, 1,1,3-trichlorodimethylsufone, hexachlorobenzene, pentachlorobenzene, chlordanes, DDT, DDE, dieldrin, hexachlorocyclohexane, mirex, photomirex, total PCBs, toxaphene, 2,4-D, 2,4,5-T, MCPA.

Note 1b: SREQMP – Sediment

*All parameters measured in SREQMP – Centrifugate Water (above), plus: alpha-chlordane, gamma-chlordane, op-DDT, pp-DDT, op-DDE, pp-DDE, pp-DD, alpha-HCH, beta-HCH, gamma-HCH, runnel, heptachlor epoxide, methoxychlor, trifluralin, triallate.

Note 2a: SREQMP Follow-up Study – Centrifugate Water

Aroclor 1016, Aroclor 1221, Aroclor 1232, Aroclor 1242, Aroclor 1248, Aroclor 1254, Aroclor 1260, Aroclor 1262, Aroclor1268, total PCBs, aldrin, alpha-BHC, beta-BHC, cis-chlordane, dieldrin, endosulfan I, endosulfan II, endosulfan I and II, endrin, gamma-BHC, heptachlor, hexachlorcyclohexane, methoxychlor, mirex, nonachlor, oxychlordane, pp-DDD, pp-DDE, pp-DDT, photomirex, quintozine, total DDE, total DDT, total chlordanes, toxaphene, trans-chlordane, hexachlorobenzene, pentachlorobenzene, 2,4,5-T, 2,4-D, bromoxynil, clopyralid, dicamba, diclofop-methyl, fenoprop, fluazifop-p-butyl, MCPA, mecoprop, picloram, triallate, triclopyr, trfluralin, EOCL, 1,1,3-trichlorodimethyl sulfone, 1,1-dichlorodimethyl sulfone, 1,2,3-trichloro-4,5,6-trimethoxybenzene, 2,3,4,5-tetrachlorophenol, 2,3,4,6-tetrachlorophenol, 2,3,4-trichlorophenol, 2,3,5,6-tetrachlorophenol, 2,3,5-trichlorophenol, 2,3,6-trichlorophenol, 2,3,-dichlorophenol, 2,4 and 2,5-dichlorophenol, 2,4,5-trichlorophenol, 2,4,6-trichlorophenol, 2,4-dichlorophenol, 2,4-dimethylphenol, 2,4-dinitrophenol, 2,6-dichlorophenol, 2,6-dichlorosyringaldehyde, 2-chlorophenol, 2-chlorosyringaldehyde, 2-nitrophenol, 3,4,5-trichlorocatechol, 3,4,5-trichloroguaiacol, 3,4,5-trichlorophenol, 3,4,5-trichloroveratrole, 3,4,6-trichlorocatechol, 3,4,6-trichloroguaiacol, 3,4-dichlorocatechol, 3,4-dichlorophenol, 3,5-dichlorophenol, 3,5-dichlorophenol, 3,6-dichlorocatechol, 3-chlorophenol, 4,5,6-trichloroguaiacol, 4,5,6-trichlorosyringol, 4,5-dichlorocatechol, 4,5-dichloroguaiacol, 4,5-dichloroveratrole, 4,6-dichloroguaiacol, 4,6-dinitro-2-methylphenol, 4-chloro-3-methylphenol, 4-chlorocatechol, 4-chloroguaiacol, 4-chlorophenol, 4-nitrophenol, 5,6-dichlorovanillin, 5-chloroguaiacol, 5-chlorovanillin, 6-chloroguaiacol, 6-chlorovanillin, m-cresol, o-cresol, p-cresol, pentachlorophenol, phenol, tetrachlorocatechol, tetrachloroguaiacol, tetrachloroveratrole, trichloromethoxybenzene, nitrobenzene-d5

Note 2b: SREQMP Follow-up Study – Sediment

*All parameters measured in SREQMP Follow-up Study – Centrifugate Water (above), plus: PCBs 100, 102, 103, 104, 105, 106, 108/86/125, 11 110 111/117, 112, 113, 114, 115, 116, 118, 12, 120, 122, 123/107/109, 124, 126, 127, 128/162, 13, 130, 131/142/133, 132, 134, 135, 136, 137, 138, 139/143, 14, 140, 141, 144, 145, 146, 147/149, 148, 15, 150, 151, 152, 153, 168, 154, 155, 156, 157, 158, 129, 159, 16, 160/163, 161, 164, 165, 166, 167, 169, 17, 170, 171, 172, 173, 174, 175/182, 176, 178, 179, 18, 180, 181, 183, 184, 185, 186, 187, 188, 189, 19, 190, 191, 192,

193, 194, 195, 197, 198, 199, 2, 200, 201/204, 202, 203/196, 205, 206, 207, 208, 209, 21/20/33, 22, 23, 24, 25, 26, 27, 28, 29, 3, 30, 31, 32, 34, 35, 36, 37, 38, 39, 4/10, 40/68, 41, 43/52, 44, 45, 46, 47, 48/49, 5, 50, 51, 53, 54, 55, 561, 57, 58/67, 59/42, 6, 60, 61, 63/76, 64, 66, 69, 7, 70, 74, 72, 73, 74, 75/65/62, 77, 78, 79, 8, 80, 81, 82, 83/119, 84,/89, 85, 87, 88/121, 9, 90/101, 91, 92, 93, 94, 95, 96, 97, 98, 99, total heptaCB, total hexaCB, total mono-triCB, total nona/decaCB, total octaCB, total PCBs, alpha-chlordane, gamma-chlordane, heptachlor epoxide, op-DDE, op-DDT, pp-DDD, ronnel, total DDD, bromine, 1,2,3,4,6,7,8,9-octachlorodibenzo-p-dioxin, 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin, 1,2,3,4,6,7,8-heptachlorodibenzofuran, 1,2,3,4,7,8,9-heptachlorodibenzofuran, 1,2,3,4,7,8-hexachlorodibenzofuran, 1,2,3,4,7,8-hexachlorodibenzofuran, 1,2,3,4,7,8-hexachlorodibenzo-p-dioxin, 1,2,3,6,7,8-hexachlorodibenzo-p-dioxin, 1,2,3,6,7-pentachlorodibenzofuran, 1,2,3,7,8,9-hexachlorodibenzo-p-dioxin, 123678 HxCDF, 12378peCDD, 12378PeCDF, 2,3,4,6,7,8-hexachlorodibenzofuran, 2,3,4,7,8-pentachlorodibenzofuran, 2,3,7,8-TCDD, 2,3,7,8-tetrachlorodibenzofuran, tetrachlorodibenzo-p-dioxin, pentachlorodibenzo-p-dioxin homologs, pentachlorodibenzo-p-dioxin (OC), hexachlorodibenzo-p-dioxin homologs, heptachlorodibenzo-p-dioxin homologs, pentachlorodibenzofuran homologs, pentachlorodibenzofurans (OC), total furans (6HxCDF), total furans (7HpCDF), octachlorodibenzofuran, total homologs, total PCDDs (OC), total PCDFs (OC), total TEQ (ND=0, 0.5, DL), total PCDDs, total PCDFs

Note 3: Alberta Environment Long-term River Network, other Organics

1,2-Diphenylhydrazine, 2,4-dimethylphenol, 2,4-Dinitophenol, 2,4-Dinitrotoluene, 2,6-Dinitrotoluene, 2-chloronaphthalene, 2-chlorophenol, 2-Methyl-46-Dinitrophenol, 2-Nitrophenol, 4-Bromophenyl, Phenyl Ether, 4-Chloro-2-Methylphenol, 4-Chloro-3-Methylphenol, 4-Chlorophenyl Phenyl Ether, 4-Nitrophenol, Bis(2-Chloroethoxy) Methane, Bis(2-Chloroeethyl) Ether, Bis(2-Chloroisopropyl) ether, Hexachlorobenzene, Hexachlorobutadiene, Hexachlorocyclopentadiene, Hexachloroethane, Isophorone, Nitrobenzene, N-Nitroso-Di-N-Propylamine, N-Nitrosodiphenylamine, Phenol, 1,1,1,2-tetrachloroethane, 1,1,1-Trichloroethane, 1,1,2,2-Tetrachloroethane, 1,1,2-Trichloroethane, 1,1-Dichloroethane, 1,1-Dichloroethylene, 1,1-Dichloropropylene, 1,2,3-Trichlorobenzene, 1,2,4-Trimethylbenzene, 1,2-Dibromo-3-Chloropropane, 1,2-Dibromoethane, 1,2-Dichlorobenzene, 1,2-Dichloroethane, 1,2-Dichloropropane, 1,3,5-trimethylbenzene, 1,3-Dichlorobenzene, 1,3-Dichloropropane, 2-chloroethylvinylether, 2-chloroethoxyethylene, 4-Chlorotoluene, Benzene, Bromobenzene, Dibromochloromethane, Bromoform, Bromomethane, Cis-1,2-Dichloroethane, Cis-1,3-Dichloropropene, Cresol (m, o, p), Dibromomethane, Dichlorobromomethane, Ethyl Benzene, Isopropylbenzene, M-+P-Xylene, Methy Tertiary Butyl Ether, Dichloromethan, N-Butylbenzene, N-Propylbenzene, O-Xylene, P-isopropyltoluene, Sec-Butylbenzene, Styrene, Tert-Butylbenzene, Tetrachloroenylene, Toluene, Trans-1,2-Dichlorotoethene, Trans-1,3-Dichloropropene, Trichloroethylene, Trichlorofluoromethane, Trihalomethanes, Vinyl Chloride, Xylene, 2,3,4,6-Tetrachlorophenol, 2,3,6-Trichlorophenol, 2,4,6-Trichlorophenol, 2,4-Dichorophenol, 3,4,5-Trichlorocatecol, 3,4,5-Trichloroguaiacol, 3,4,5-trichloroveratrol, 3,4,6-Trichlorocatechol, 3,4,6-Trichloroguaiacol, 3,4-Dichlorocatechol, 3,5-Dichlorocatechol, 4,5,6-Trichloroguaiacol, 4,5,6-Trichlorosyringol, 4,5-Dichlorocatechol, 4,5-Dichloroguaiacol, 4,5-Dichloroveratrole, 4,6-Dichloroguaiacol, 4-chlorocatechol, 4-Chloroguaiacol, 4-Chlorophenol, Bromacil, Bromoxynil, Carbathiin (Carboxin), Cyanazine, Diazinon, Diclofop-Methyl (Hoegrass), Disulfoton (Di-Syston), Diuron, Chlorpyrifos-Ethyl (Dursban), Ethalfluralin (Edge), Ethion, Guthion , Clopyralid (Lontrel), Malathion, MCPA, MCPB ,MCPP (Mecoprop), Picloram (Tordon), Phorate (Thimet), Terbufos, Triallate (Avadex BW), Trifluralin (Treflan), Imazamethabenz-Methyl, Desethyl Atrazine, Desisopropyl Atrazine, Quinclorac, Imazethapyr, Fenoxaprop-P-Ethyl, Pyridaben, Dimethoate (Cygon), Pentachlorophenol, Tetrachlorocatecol, Tetrachloroguaiacol, Tetrachloroveratrol, 12,14-Dichlorodehydroabietic Acid, 12-Chlorodehydroabietic Acid, 14-Chlorodehydroabietic Acid, Abietic Acid, Dehydroabietic Acid, Isopimaric Acid, Levopimaric Acid, Neoabietic Acid, Palustric Acid, Pimaric Acid, Sandaracopimaric Acid, 2,4-D (Dichlorophenoxyacetic Acid), 2,4-DB, Dichlorprop (2,4-DP), Alpha-Benzenehexachloride (BHC), Alpha-Endosulfan, γ-

Hexachlorocyclohexane (Lindane), Methoxychlor (P,P'-Methoxychlor), Atrazine, Aldrin, Dieldrin, Metolachlor, Imazamox, Parathion, Metribuzin, Dicamba, Simazine, Triclopyr, Aminopyralid, Napropamide, Thiamethoxam, Vinclozolin, Oxycarboxin, Methomyl, Aldicarb, Clodinafop-Propargyl, Clodinafop Acid Metabolite, 4-Chloro-2-Methylphenol, 2,4-Dichlorophenol, Chlorothalonil, Iprodione, Popiconazole, Hexaconazole, Metalaxyl-M, Fluazifop, Fluroxypyr, Quizalofop, Bentazon, Ethofumesate, Linuron, Adsorbable Organic Halide AOX.

Note 4: Bourbonniere *et al.*, 1996

T4CD, P5CDD, H6CDD, H7CDD, O8CDD, T4CDF, P4CDF, H6CDF, H7CDF, O8CDF, T4CDF

Note 5: Evans *et al.*, 1996

PCBs 1, 3, 04/10, 6, 7, 08/05, 16/32, 17, 18, 19, 22, 24/27, 25, 26, 28, 31, 33, 40, 41/71, 42, 44, 45, 46, 47, 48, 49, 52, 56,/60, 64, 70/76, 74, 82, 84/89, 83, 85, 87, 91, 95, 97, 99, 101, 110, 114, 118, 128, 130, 176, 131, 132, 136, 138, 141, 144/135, 146, 149, 151, 153, 158, 137, 156, 170, 174, 177, 178/129, 179, 180, 183, 187, 191, 193, 199, 201/157, total PCBs, 902,7/2,8-DiCDD, 2,3-DiCDD, 2,3,7-TriCDD, 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, 1,2,3,4,7,8-HxCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, total PCDD, OCDD, 2,8-diCDF, 2,3,8-triCDF, 2,3,7,8-TCDF, 1,2,3,7,8-PeCDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, 2,3,4,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF, 1,2,3,4,6,7,8,-HpCDF, 1,2,3,4,7,8,9-HpCDF, total PCDF, OCDF, hexachlorohexane, pentachloroanisole, trichloroveratrole, tetrachloroveratrole, op-DDE, pp-DDE, op-DDD, pp-DDD, op-DDT, pp-DDT, total DDT.

Note 6: Crosley 1996

Pimaric acid, Sandaracopimaric acid, Isopimaric acid, Palustric acid, DHI, DHA, Abietic acid, Neoabeitic acid, 12/14 C1-DHA, 12,14-DiCl-DHA, Total resin acids, M1CDD, D2CDD, T3CDD, T4CDD, P5CDD, H6CDD, H7CDD, O8CDD, M1CDF, D2CDF, T3CDF, T4CDF, P5CDF, H6CDF, H7CDF, O8CDF, 4-CP, 2,6-DCP, 2,4/2,5-DCP, 3,6-DCP, 2,3-DCP, 3,4-DCP, 6-CG, 5-CG, 2,4,6-TCP, 2,3,6,-TCP, 2,3,5-TCP, 2,4,5-TCP, 2,3,4-TCP, 3,4,5-TCP, 3-CC, 4-CC, 4,6-DCG, 3,4-DCG, 4,5-DCG, 3-S, 3,6-DCG, 3,5-DCC, 3,4-DCC, 4,5-DCC, 2,3,5,6-TCP, 2,3,4,6-TCP, 2,3,4,5-TCP, 5-CV, 6-CV, 3,5,-DCS, 3,4,6-TCG, 3,4,5-TCG, 4,5,6-TCG, 3,4,6-TCC, 3,4,5-TCC, 5,6-DCV, PCP, 2-CSA, 3,4,5,6-TCG, 3,4,5-TCS, 3,4,5,6-TCC, 2,6-DCSA, Aroclor 1242, Aroclor 1254, Aroclor 1260, PCB #77, PCB#126, PCB#169, Extractable organic halogen, Toxaphene.

Note 7: Brownlee *et al.*, 1996

TCDD, PeCDD, HxCDD, HpCDD, TCDF, PeCDF, HxCDF, HpCDF, 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, OCDD, 2,3,7,8-TCDF, 1,2,3,7,8-PeCDF, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, 1,2,3,4,6,7,8-HpCDF, OCDF, Pimeric acid, Sandaracopimaric acid, Ispimeric acid, Palustric acid, Dehydroisopimaric acid, Dehydroabietic acid, Abietic acid, Neoabietic acid, 12/14-Chlorodehydroabietic acid, 12,14-Dichloriodehydroabietic acid, 4-Chlorocatechol, 2,4,-Dichlorocatechol, 3,4,5-Trichlorocatechol, 3,4,6-Trichlorocatechol, Tetraclorocatechol, 5-Chlorovanillin, 6-Chlorovanillin, 3,4,5-Trichloroguaiacol, 3,4,5-Trichloroveratrole, 2-Chlorosyringaldehyde.

Note 8: Milburn and Prowse 1998

PCBs 7, 6, 8/5, 19, 18, 17, 24/27, 16/32, 26/25, 31/28, 21/33/53, 22, 45, 46, 52/43, 49, 47/48, 44, 42, 41, 71, 64, 40, 63, 74, 70, 76, 66, 95, 91, 56, 60, 89, 84, 101, 99, 83, 97, 81/87, 85/136, 77/110, 82, 151, 144/135/147/107, 149, 118, 134/114, 146, 153/132, 105, 141, 137, 176/130, 138/158/178/129, 175, 187/182, 183, 128, 167, 185, 174, 177, 171/156, 157, 173, 172/197, 180,

199, 170/197, 180, 199, 170, 190, 201, 203/196, 195, 194, 206, total PCBs, 2-monochlorophenol, 3,5-dichlorophenol, 2,3-dichlorophenol, 2,3,5-trichlorophenol, 2,4,5-trichlorophenol, 3,4,5-trichlorophenol, pentachlorophenol, trichlorosyringol, 3,4,5,6-tetrachlorocatechol, 3,4,5-triguaiacol, 3,4,5,6-tetraguaiacol, 5,6-dichlorovanillin, total CPPs, 2,3,7,8-TCDD, 1,2,3,7,7-PeCDD, 1,2,3,4,7,8-HxCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, OCDD, 2,3,7,8-TCDF, 1,2,3,7,8-PeCDF, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, 2,3,4,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF, 1,2,3,4,6,7,8-HpCDF, 1,2,3,4,7,8,9-HpCDF, OCDF, total furans, total dioxins/furans, TEQ

Note 9: Noton and Shaw 1989

2,4-dichlorophenol, 2,4,6-trichlorophenol, benzoic acid, hexadecanoic acid, 1,1,1-trichloroethane, carbontetrachloride, chloroform, ethylbenzene, mp-xylne, styrene, toluene, dichloroguaicol, guaicol, tetrachloroguaicol, trichloroguaicol vanillin, 1-n-inden-1-1,2,3-dihydro-3,3,4,7-tetramethyl, 1-methyl-2-benzene, 2-pentylfuran, 4-trimethyl-3-cyclohexene-1-methanol, 5-nonen-2-one, acetophenone, alpha-pinene and isomers, alpha-terpinol, camphor, dichlorodimethyl sulfone, dimethoxybenzene, dimethylcyclopentenone, dimethyldisulfide, dimethyltrisulfide, isopropylbenzene methanol, methylbenzene methanol, methyl isopropenyl benzene, p-cymen-8-ol, terpineol, trichlorodifluoroethane, trimethyldimethylethyl-ethylbenzene methanol, trimethylcyclopentenones, 4-hydroxy-3-methoxybenzaldehydem 2-pentylfuran, 2,2,3-trimethylhexane, methylcyclohexadiene, methyl cyclohexane, methyl pentane, methylene cyclohexane, chloroform, styrene, diacetyl benzofuran, dipropyl benzene, 1-(4-ydroxy-3,5-dimethoxyphenol)-ethanone, 1n-indole, 2-chloro-1-phenyl ethanone,dihydroxyacetophenone, dimethylcyclohexene, methylcyclopentanone, tributyl phosphate, trichlorodifluroethane, tetra-1,1-dioxide thiophene.

Sub-Table A.1: Citations for Monitoring Program and Research Study Report Numbers. This lists the AOSERP, NRBS and NREI studies that are listed by report number in the information table (Appendix 1) above. Other studies are cited within the table. References for the citations below, and those in the above table can be found in the Literature Cited section of this document.

Report #	Program	Citation
2	AOSERP	Kristensen *et al.* (1975)
17	AOSERP	Lutz and Hendzel (1976)
18	AOSERP	Loeppky and Spitzer (1977)
34	AOSERP	Allan and Jackson (1978)
40	AOSERP	Beltaos (1979)
60	AOSERP	Neill and Evans (1979)
71	AOSERP	Hesslein (1979)
89	AOSERP	Bond (1980)
123	AOSERP	Neill *et al.* (1981)
L74	AOSERP	Akena and Christian (1981)
L85	AOSERP	Corkum (1985)
9	NRBS	Boag (1993)
20	NRBS	Balagus *et al.* (1993)
26	NRBS	Smithson (1993)
43	NRBS	Aitken and Sapach (1994)
61	NRBS	Jacobson and Boag (1995)
71	NRBS	Bourbonniere *et al.* (1996a)
72	NRBS	Bourbonniere *et al.* (1996b)

Report #	Program	Citation
74	NRBS	English *et al.* (1996)
76	NRBS	Hicks *et al.* (1996a)
77	NRBS	Hicks *et al.* (1996b)
99	NRBS	Evans *et al.* (1996)
102	NRBS	Church (1996)
103	NRBS	Prowse *et al.* (1996)
106	NRBS	Crosley (1996)
112	NRBS	Golder Associates Ltd. (1995)
119	NRBS	Tallman (1996)
122	NRBS	Andres (1996)
131	NRBS	Evans (1996)
134	NRBS	Brownlee (1996)
135	NRBS	Dobson (1996)
136	NRBS	Golder Associates Ltd. (1997b)
146	NRBS	Choles (1996)
17	NREI	Pietroniro *et al.* (2004)
26	NREI	Milburn and Prowse (1998)
66	NREI	Pietroniro and Töyrä (2004)

Sub-Table A.2: Website references indicated by letter in the information table (Appendix 1), above.

Cell Reference	Website
A	http://environment.alberta.ca/01288.html
B	http://www.env.gov.bc.ca/epd/wamr/ems_internet/index.html
C	http://www.ainc-inac.com/ai/scr/nt/env/wr/dt/ss/index-eng.asp
D	http://www.environment.alberta.ca/forecasting/data/snow/apr2011/plainsscdatarank.html
E	http://www.ec.gc.ca/rhc-wsc/default.asp?lang=En&n=4EED50F1-1
F	http://bcrfc.env.gov.bc.ca/bulletins/
G	http://www.bchydro.com/about/our_system/hydrometric_data/peace.html.

www.ec.gc.ca

Additional information can be obtained at:

Environment Canada
Inquiry Centre
10 Wellington Street, 23rd Floor
Gatineau QC K1A 0H3
Telephone: 1-800-668-6767 (in Canada only) or 819-997-2800
Fax: 819-994-1412
TTY: 819-994-0736
Email: enviroinfo@ec.gc.ca